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TURKISH JOURNAL OF
ORTHODONTICS

Original Article

Condylar Morphology in Patients with Unilateral Maxillary Impacted Canines: A Panoramic Radiography Study

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Main Points

- The results of this study suggest that in individuals with a unilateral maxillary impacted canine, the absence of canine-protected occlusion alone may not be associated with side-dependent differences in mandibular condylar morphology.
- The symmetrical distribution of condylar shapes indicates that any adaptive morphological patterns are unlikely to be side-dependent in patients with unilateral canine impaction.
- These findings reinforce the multifactorial nature of temporomandibular joint adaptation, in which occlusion represents only one of several contributing factors.

ABSTRACT

Objective: The aim of this study was to evaluate the association between unilateral maxillary impacted canines (UMIC) and condylar morphology by comparing ipsilateral and contralateral condyles within affected individuals using panoramic radiography.

Methods: This retrospective cross-sectional study included 364 patients with UMIC (169 with impacted right canines and 195 with impacted left canines). Panoramic radiographs were used to evaluate mandibular condylar morphology. Condyles were classified into four categories (round, angled, flat, and pointed) and additionally dichotomized as round or non-round for binary comparisons. Paired ipsilateral and contralateral comparisons were performed using McNemar's test for binary outcomes with analyses stratified by age (<20 and ≥20 years). Statistical significance was set at p<0.05.

Results: Age-stratified McNemar analyses demonstrated no statistically significant side-related differences in binary condylar morphology (round vs. non-round) between ipsilateral and contralateral sides of the patients (p>0.05). Descriptive evaluations showed that round condylar morphology was less prevalent in patients aged ≥20 years, whereas angled and pointed morphologies were more frequently observed compared to those aged <20 years, on both the ipsilateral and contralateral sides.

Conclusion: Based on the present findings, UMIC alone does not appear to be associated with side-specific differences in condylar morphology. Further studies using advanced three-dimensional imaging techniques are needed to better characterize condylar morphology.

Keywords: Panoramic radiography, condylar morphology, impacted canines

INTRODUCTION

The impact of occlusal relationships on the temporomandibular joint (TMJ) remains a debated topic.[1] One of the key concepts in this discussion is canine-protected occlusion (CPO), which is believed to play a crucial role in minimizing adverse occlusal forces affecting the TMJ. In CPO, during lateral jaw movements, only the canines (and possibly the first premolars) come into contact, protecting the other teeth from harmful forces. This occlusal relationship is considered the ideal functional occlusion for natural dentition and is often the goal for restorative and orthodontic treatments.[2] Previous studies have shown that the electromyographic (EMG) activity of the temporalis and masseter muscles is lower during

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lateral excursions in patients with CPO, suggesting better muscle function. This finding contrasted with those with group function occlusion, in whom higher muscle activity was observed.[3] These results were further substantiated by research showing that CPOs do not result in significant alterations in muscle activity during mastication but notably decrease muscle activity during parafunctional clenching.[4] It was proposed that CPO, as opposed to group function, leads to minimal EMG activity and, consequently, to the least occlusal loading. Additionally, several studies have suggested that the canines may play a unique proprioceptive role, which helps reduce muscle activity and further minimize occlusal loading.[5] Given the central functional role attributed to the canines in occlusal guidance, alterations in canine position or in eruption patterns may influence occlusal dynamics. In cases of unilateral impacted maxillary canines, the question arises whether such occlusal asymmetry is associated with side-specific morphological patterns of the TMJ.

The TMJ is one of the most significant and distinctive joints in the body. It is a freely movable joint formed between the mandibular condyle and the squamous part of the temporal bone at the base of the skull.[6] The size and shape of the components of the TMJ, as well as their relationship to one another, can vary significantly. It is commonly believed that a normal, healthy condylar head should have a consistently convex, oval shape and that there should be symmetry between the contralateral sides of the same individual. Various studies have assessed the morphology of human mandibular condyles, noting differences in their shapes.[7]

The proper functioning and health of the TMJ are essential for daily life. The main roles of the TMJ are to allow smooth, efficient movement of the mandible during functions such as chewing, swallowing, and speaking; to ensure the stability of the mandibular position; and to prevent dislocation caused by external or unusual forces. The condyle plays a key role in mandibular growth.[8] The fundamental morphology of the mandibular condyle is believed to be established early and may undergo morphological adaptation throughout life in response to functional forces. Condylar remodeling is a natural process that adjusts the TMJ structure to accommodate functional needs. This process involves a dynamic interaction between the mechanical forces acting on the TMJ and the ability of the condyle to adapt. Even after growth is complete, TMJ components are believed to retain the capacity to remodel, thereby continually altering their structure and shape.[8]

Given the adaptive capacity of the TMJ and the potential influence of functional and occlusal factors on condylar morphology, TMJ-related considerations have gained increasing attention in orthodontic diagnosis and treatment planning. In their recent study, Kamar Alden et al.[9] emphasized the potential importance of early crossbite intervention in the context of temporomandibular disorder risk. A recent systematic review and meta-analysis highlighted the impact of temporomandibular disorders on orthodontic management and the importance of careful TMJ assessment in orthodontic patients.[10]

This study aims to evaluate condylar morphology in individuals with unilateral maxillary impacted canines (UMIC) by comparing ipsilateral and contralateral condyles on panoramic radiographs to determine whether side-specific morphological differences are present. The null hypothesis was that there would be no significant difference in condylar morphology between the ipsilateral and contralateral sides of individuals with UMIC.

METHODS

This retrospective cross-sectional study, including the radiographic evaluations of 364 patients, was approved by an institutional Marmara University Faculty of Dentistry Clinical Studies Ethics Committee (approval number: 2025-09-02/2025-64, date: 31.07.2025). All panoramic radiographs (orthopantomograms) included in this retrospective study were acquired using the same panoramic radiographic unit (Planmeca ProMax 2D, Planmeca, Helsinki, Finland) with exposure settings of 5 mA and 66 kV. Radiographs were obtained between 2015 and 2023, and the inherent manufacturer-stated magnification error of the device was accepted without additional correction. Radiographs were obtained with patients in an upright position, and head positioning was performed according to routine clinical practice, to align the Frankfort horizontal plane parallel to the floor. All images were selected from radiographs acquired under comparable projection and positioning conditions.

Panoramic radiographs were included if they provided clear, complete visualization of both mandibular condyles without projection errors and a UMIC was present. Radiographs demonstrating pathological conditions, fractures, developmental anomalies, craniofacial syndromes, fixation hardware, or other factors potentially affecting condylar morphology were excluded. A detailed description of the inclusion and exclusion process is presented in Figure 1.

A total of 364 panoramic radiographs meeting these criteria were randomly selected from the institutional archive. In the study sample, 239 patients (65.7%) were female and 125 (34.3%) were male. The mean age of the overall sample was 25.07±11.45 years. When patients were stratified by age, 175 were younger than 20 years, whereas 189 were 20 years or older (Table 1).

Condylar morphology was assessed by a single experienced orthodontist under standardized viewing conditions using a 24-inch medical-grade monitor (1920×1080 resolution) in a dimly lit environment. The examiner was blinded to the side of canine impaction during image evaluation. To assess reliability, a randomly selected subset of radiographs (20%) was re-evaluated after a two-month interval to assess intra-observer agreement and was independently evaluated by a second orthodontist to assess inter-observer agreement. Reliability was quantified using Cohen's kappa coefficient. According to the calculations, intra-observer agreement ranged from

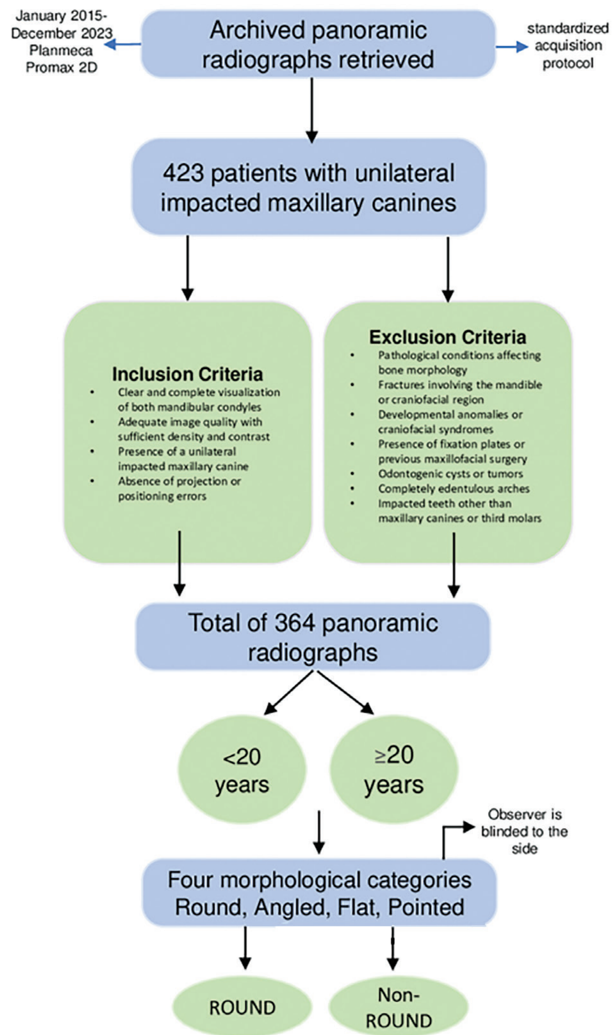

Figure 1. Flow diagram of sample selection and exclusion process.

substantial to excellent (Cohen's κ=0.74-0.82), while inter-observer agreement was substantial (κ=0.72-0.78).

The final sample consisted of 728 condyles from 364 individuals, including 169 patients with impacted right canines and 195 with impacted left canines. Each patient contributed two condyles, which were categorized as ipsilateral or contralateral relative to the side of canine impaction.

For descriptive analysis, condylar shapes were visually categorized as round, angled, flat, or pointed according to previously published morphological criteria.[11] For analytical purposes, this four-category classification of condylar morphology was dichotomized into round and non-round categories to enable paired statistical comparisons. Round morphology was defined as a smooth, convex condylar outline, whereas the non-round category included flat, angled, and pointed morphologies (Figure 2).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize the demographic variables, including age and sex.

For the binary classification of condylar morphology (round vs. non-round), side-related differences between ipsilateral and contralateral condyles were evaluated using McNemar's test for paired categorical comparisons. All tests were two-tailed, and statistical significance was set at $p<0.05$.

Age-related differences in the distribution of ipsilateral and contralateral condylar morphology across four shape categories were evaluated using the Pearson chi-squared test.

Based on the differences in the distribution of condylar morphology across age groups reported in a previous study, an a priori power analysis was conducted using the G*Power software (version 3.1.9.6; Heinrich-Heine-Universität, Düsseldorf, Germany). A sample size of 251 individuals was required to achieve 95% power at α=0.05 for an effect size of 0.272.[12]

RESULTS

In patients under 20 years of age, paired comparisons of ipsilateral and contralateral condylar morphology showed no statistically significant side-related difference. As presented in Table 2, discordant pairs were observed in equal numbers in the ipsilateral round/contralateral non-round and ipsilateral non-round/contralateral round categories (25 vs. 25). McNemar's test revealed no significant difference between sides ($p=0.89$), with a matched odds ratio of 1.00 [95% confidence interval (CI): 0.57-1.74].

Among patients aged 20 years and older, paired analyses similarly demonstrated no statistically significant difference between ipsilateral and contralateral condylar morphologies (Table 3). Although discordant pairs were numerically higher in the ipsilateral non-round/contralateral round category than in the opposite category (30 vs. 22), this difference was not

Table 1. Demographic characteristics of the study population

Age group	Female (n, mean±SD)	Male (n, mean±SD)	Total (n, mean±SD)
<20 years	120 (15.97±2.01)	55 (16.08±1.84)	175 (16.01±1.95)
≥20 years	119 (32.05±9.75)	70 (35.85±10.37)	189(33.46±10.13)
Total	239 (23.98±10.68)	125 (27.15±12.59)	364 (25.07±11.45)

Values are presented as n (mean ± standard deviation).
SD, standard deviation.

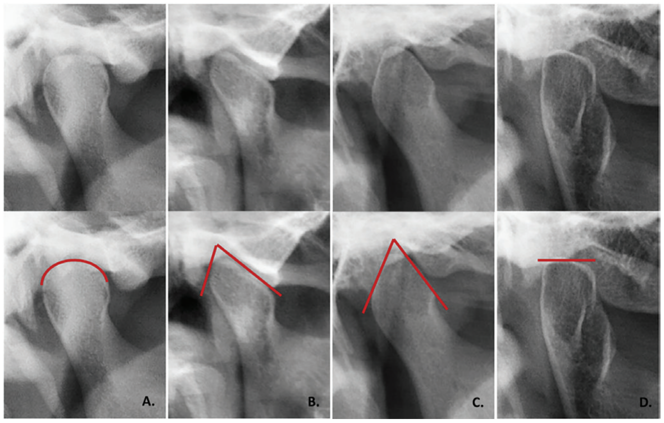

Figure 2. The condyle morphology classification[11] (A) Round: symmetrical condylar outline with smooth, continuous, and convex anterior, superior, and posterior surfaces; (B) Angled: asymmetrical, with an acute angle at the posterior surface; (C) Pointed: symmetrical, with an acute angle at the midpoint of the superior surface (D) Flat: Flattened superior surface extending from the anterior to the posterior aspect of the condylar head.

statistically significant (McNemar's test, $p=0.33$). The matched odds ratio was 1.36 (95% CI: 0.79-2.36).

Accordingly, no statistically significant side-specific differences in condylar morphology were observed in either age group, and the null hypothesis could not be rejected.

The distribution of condylar shape classifications (round, angled, flat, and pointed) according to age groups (<20 years and ≥20 years) on the ipsilateral and contralateral sides is presented in Tables 4 and 5. The Pearson chi-squared test demonstrated a significant association between age group and condylar shape distribution on both the ipsilateral ($p<0.001$) and contralateral sides ($p<0.001$).

In patients aged <20 years, round condylar morphology was the most frequently observed category on both sides.

Table 2. Paired ipsilateral-contralateral condylar morphology in patients under 20 years

	Contralateral round	Contralateral non-round	p
Ipsilateral round	74	25	0.89
Ipsilateral non-round	25	51	

Paired comparisons were performed using McNemar's test. Statistical significance was set at $p<0.05$.

Table 3. Paired ipsilateral-contralateral condylar morphology in patients aged 20 years and older

	Contralateral round	Contralateral non-round	p
Ipsilateral round	26	22	0.33
Ipsilateral non-round	30	111	

Paired comparisons were performed using McNemar's test. Statistical significance was set at $p<0.05$.

In contrast, among patients aged ≥20 years, the relative frequency of round morphology was reduced, whereas angled morphology became the most prevalent category on both the ipsilateral and contralateral sides. Pointed condylar morphology was observed more frequently in the ≥20 years group on the ipsilateral side, whereas its distribution on the contralateral side showed a similar trend without a distinct predominance.

DISCUSSION

Condyle remodeling is influenced by more than occlusal loading alone; therefore, CPO cannot be singled out as the sole cause. Factors such as age, sex, and genetics also play a role in this complex process.[13] As with TMJ disorders, pinpointing a single cause is challenging, these conditions are multifactorial.[14] The interplay of these elements makes it difficult to eliminate one factor without considering the broader context of the individual's health and predispositions.

To the best of our knowledge, there are no previous studies specifically investigating the relationship between impacted canines and condylar morphology. Although some studies have examined condylar alterations associated with general occlusal disturbances, none have focused exclusively on impacted canines.[15,16] While panoramic radiography has been considered sufficient for certain morphological assessments in previous studies,[17] these investigations have largely relied on two-dimensional imaging techniques and therefore provide limited information regarding three-dimensional osseous structures. Supporting this limitation, a recent comparative study that evaluated panoramic radiographs and cone-beam computed tomography (CBCT) for condylar morphology assessment showed that flat, pointed, and round condylar morphologies identified on panoramic radiographs were

Table 4. Distribution of condylar shape categories on the ipsilateral side according to age group

Ipsilateral	<20 years	≥20 years	p
Round	**99 (56.6%)****	**48 (25.4%)****	p<0.001
Angled	**44 (25.1%)****	**90 (47.6%)****	
Flat	11 (6.3%)	11 (5.8%)	
Pointed	**21 (12.0%)***	**40 (21.2%)***	

Chi-square test *$p<0.05$ **$p<0.001$. Bold letters mean statistically significant differences.

Table 5. Distribution of condylar shape categories on the contralateral side according to age group

Contralateral	<20 years	≥20 years	p
Round	**99 (56.6%)***	**56 (29.6%)***	p<0.001
Angled	**47 (26.9%)***	**88 (46.6%)***	
Flat	8 (4.6%)	9 (4.8%)	
Pointed	21 (12.0%)	38 (19.0%)	

Chi-square test *$p<0.001$. Bold letters mean statistically significant differences.

confirmed by CBCT, whereas the angled morphology did not appear to correspond to a true anatomical condylar shape.[11] In this context, the study offers descriptive insights into condylar morphology in patients with impacted canines. However, given the inherent limitations of panoramic radiographs in capturing three-dimensional morphology, further studies using advanced imaging modalities, such as CBCT, are warranted to validate these observations and to enable more detailed morphological assessment, as supported by recent CBCT-based orthodontic imaging studies.[18]

The popularity of CPO has led many to treat it as an established fact, despite the lack of conclusive evidence supporting it as the ideal functional occlusion. Clark and Evans[19] emphasized that the criteria for an "ideal" occlusion remain undefined, and the validity of CPO, alongside group function and balanced occlusion, remains questionable, as not all individuals function in the extreme border positions that CPO represents. Accordingly, it is difficult to attribute non-round condylar morphologies observed in some patients to a single occlusal factor. Rather, such morphological variations are more likely to reflect the combined influence of functional loading, age-related adaptation, and individual biological variability. Further research is required to clarify the relationship between occlusal characteristics and condylar remodeling.

According to our results, there were no statistically significant side-related differences between ipsilateral and contralateral condyles in either age group. In patients younger than 20 years, discordant pairs were equally distributed between the left and right sides, indicating symmetrical condylar morphology. Similarly, among patients aged 20 years and older, a numerically higher frequency of ipsilateral non-round morphology was observed; however, this difference was not statistically significant. Based on these outcomes, unilateral maxillary canine impaction alone does not appear to result in consistent side-dependent alterations in condylar morphology detectable on panoramic radiographs. The absence of significant asymmetry across age groups supports the concept that condylar morphology reflects adaptive or anatomical variation rather than localized occlusal imbalance associated with the side of canine impaction.

Analysis of the age-stratified distribution of condylar morphology revealed distinct patterns between younger and older patients, with comparable distribution trends observed on the ipsilateral and contralateral sides. In patients younger than 20 years, round condylar morphology predominated bilaterally, followed by angled, pointed, and flat forms. In contrast, among patients aged 20 years and older, the relative frequency of round condyles was lower, angled morphology became the most prevalent category, and pointed morphology was observed more frequently in these patients, particularly on the ipsilateral side. Notably, flat morphology remained the least common shape in both age groups. The similar distribution patterns observed on ipsilateral and contralateral sides within each age group indicate that these variations are more likely related to age-associated adaptive or maturational changes rather than to side-specific functional or occlusal asymmetry associated with unilateral canine impaction.

The observed distribution of condylar shape categories showed that round and angled morphologies were encountered more frequently than flat and pointed forms, consistent with previous studies reporting these shapes as common anatomical variations in healthy populations. For example, in their assessment of mandibular landmarks in a North Indian population, Bains et al.[20] also reported that oval and angled condyles were the two most frequently observed morphologies, indicating that these shapes likely represent common anatomical variants rather than pathological alterations. The distribution of condylar morphology appeared similar on the ipsilateral and contralateral sides among the patients included in this study. This observation suggests that the occurrence of different morphological variants may reflect natural variation within the population rather than being related to the side of canine impaction. Comparisons to previous studies provide additional context for the observed variability in condylar shape distribution. In their radiographic survey evaluating condylar morphology, Singh et al.[21] reported oval (round) condyles as the most common morphology, similar to the results of this study. Nevertheless, differences in the relative frequency of secondary morphological categories were noted: pointed condyles were reported as the second most prevalent form in their study, whereas angled morphology was more frequently observed in the sample of this study. Such variations may be attributed to population characteristics.

The symmetrical distribution observed in this study implies that condylar morphology in individuals with impacted canines may reflect inherent morphological variation within the studied population rather than a consistent side-related pattern. However, given the cross-sectional design of this study, potential remodeling processes could not be attributed to a single factor and are likely influenced by multiple contributing mechanisms.

Age is an important factor to consider in the evaluation of condylar morphology and potential remodeling processes. As age increases, the impact of occlusal loading on the condyle becomes more pronounced due to prolonged mechanical stress, leading to more noticeable changes in the bone structure,[22,23] which can be more easily observed on panoramic radiographs. In this study, age-stratified analyses revealed distinct distribution patterns of condylar morphology in younger versus older patients, suggesting that the observed variations may reflect maturational or adaptive changes over time. These findings emphasize the importance of accounting for age when interpreting radiographic assessments of condylar morphology and support the need for longitudinal studies to further clarify age-related remodeling processes.

From a clinical perspective, the findings of this study indicate that UMIC alone should not be interpreted as an indicator of side-specific condylar morphological alteration on panoramic radiographs. This may help clinicians avoid the overinterpretation of routine radiographic findings and unnecessary concern regarding TMJ morphology in asymptomatic patients. Nevertheless, a comprehensive clinical evaluation of the TMJ remains appropriate in patients with impacted canines, particularly when clinical signs or symptoms are present.

Study Limitations

The limitations of this study include its cross-sectional design and reliance on panoramic radiographs, which may not have captured condylar morphology as accurately as CBCT. Panoramic radiographs are subject to inherent, non-uniform magnification related to projection geometry and patient positioning, which may represent a source of measurement or classification bias. However, because this study relied on descriptive morphological categorization rather than absolute linear measurements, the impact of this limitation is expected to be minimal.

Another limitation is the absence of a matched non-impacted control group, which prevents direct comparison of morphological distributions and limits interpretation of relative prevalence. Furthermore, clinical TMJ variables, such as pain, joint sounds, functional limitations and standardized DC/TMD-based clinical assessments, were not evaluated, thereby restricting the interpretation of the findings to radiographic morphology. Although age-stratified analyses were performed, the cross-sectional design limits the interpretation of age-related differences in condylar morphology. Future studies should utilize advanced imaging modalities, standardized clinical TMJ assessments, and longitudinal designs to better clarify the potential relationships between impacted canines and TMJ morphology.

CONCLUSION

In patients with UMIC, condylar morphology was largely symmetrical between the ipsilateral and contralateral sides. These findings indicate that unilateral canine impaction alone is unlikely to be associated with side-specific condylar morphological patterns on panoramic radiographs. Differences in morphological distribution across age groups suggest that condylar shape variability may be influenced by age-related factors rather than by localized occlusal asymmetry. Further longitudinal studies using three-dimensional imaging modalities and matched control groups are needed to clarify the clinical relevance of these observations.

Ethics

Ethics Committee Approval: The study was approved by Marmara University Faculty of Dentistry Clinical Studies Ethics Committee (approval number: 2025-09-02/2025-64, date: 31.07.2025).

Informed Consent: Informed consent was waived due to the retrospective nature of the study.

Footnotes

Presented in: This study was presented at the 19th International Turkish Orthodontic Society Symposium.

Author Contributions: Concept - B.T.M.; Design - B.T.M.; Data Collection and/or Processing - A.Y.A.; Analysis and/or Interpretation - A.Y.A.; Literature Search - B.T.M., A.Y.A.; Writing - B.T.M.

Conflict of Interest: No conflict of interest was declared by the authors.

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Original Article

Comparative Assessment of Dimensional Accuracy and Fit of Aligners Manufactured by Direct Printing and Thermoforming: An *in vitro* Study

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Cite this article as: Felix N, Nagesh S. Comparative assessment of dimensional accuracy and fit of aligners manufactured by direct printing and thermoforming: an *in vitro* study. *Turk J Orthod.* 2026; 39(2): 59-66

Main Points

- Direct-printed aligners made with TA-28 resin showed superior dimensional accuracy compared to thermoformed polyurethane (PU) and polyethylene terephthalate glycol-modified (PET-G) aligners.
- Direct-printed aligners showed significantly lower deviations at all nine bilateral anatomical landmarks assessed.
- PU-based thermoformed aligners exhibited smaller deviations at all nine landmarks than PET-G.
- The elimination of intermediate fabrication steps in direct printing contributes to improved dimensional accuracy and clinical fit.

ABSTRACT

Objective: The objective of the study was to compare the accuracy and fit of direct-printed and thermoformed aligners.

Methods: The *in vitro* study included a pre-treatment scan as a reference model. Thirteen successive treatment stages were digitally planned and exported as Standard Tessellation Language (STL) files. Based on the treatment plan, 39 aligners were manufactured for three groups: Group 1, direct-printed aligners with TA-28 resin; Group 2, thermoformed polyurethane (PU) aligners; and Group 3, thermoformed polyethylene terephthalate glycol-modified (PET-G) aligners. All aligners were subsequently scanned, and the resulting STL files were superimposed on the baseline models. The dimensional accuracy and fit of the aligners were evaluated. The groups were compared using the Kruskal-Wallis test, followed by Dunn-Bonferroni post-hoc comparisons, with significance set at $p \leq 0.05$. Intra-rater and inter-rater reliability were evaluated via intraclass correlation coefficients.

Results: Group 1 exhibited greater dimensional accuracy, as evidenced by the lowest mean deviation compared with Groups 2 and 3 ($p<0.001$). Pairwise comparisons indicated significant differences between Group 1 and Group 2 and between Group 1 and Group 3 ($p<0.001$); however, no significant difference was found between Groups 2 and 3 ($p=0.489$). Landmark-based deviation analysis indicated that Group 1 demonstrated the least deviation across all nine evaluated anatomical landmarks ($p<0.001$). Group 3 showed slightly greater deviations than Group 2 for most landmarks.

Conclusion: Direct-printed aligners fabricated using TA-28 resin exhibited significantly higher dimensional accuracy and a better fit than thermoformed aligners manufactured from PU and PET-G.

Keywords: Computer-aided design, dimensional accuracy, orthodontic appliances, three-dimensional printing, polymers

INTRODUCTION

Clear aligner therapy has gained popularity among patients due to its aesthetic appeal.[1] It also offers enhanced comfort for patients due to the seamless fit, hence diminishing the probability of soft tissue irritation and facilitating easier oral hygiene maintenance compared with conventional braces.[2,3] The advancements in computer-aided design and manufacturing (CAD/CAM) have fueled this increasing demand for aligners.[4] Traditionally, clear aligners were fabricated

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through a thermoforming process, where thermoplastic sheets were vacuum-formed over digitally planned and 3D-printed dental models.[5] Various aligner sheets, software, printers, and thermoforming machines are available on the market, each with distinct specifications and characteristics. Thermoformed aligner treatment fundamentally relies on the properties of the plastic sheets used, the thermoforming process, and the precision of dental model printing.[6] Previous research has shown that the thermoforming process itself can cause alterations in the physical and mechanical properties of the aligners.[7,8] In response to these issues, direct-printed aligners have emerged as a notable technological advancement in aligner orthodontics. These aligners are manufactured using additive 3D printing techniques, such as digital light processing (DLP) or stereolithography, directly from digital models without the intermediary step of model printing and thermoforming.[9] By eliminating these additional fabrication stages, direct-printed aligners theoretically offer higher dimensional accuracy, improved adaptation to the dentition, and more predictable force delivery.[10] Furthermore, they reduce waste and time in the production workflow, making them particularly attractive for in-house aligner systems.[11]

Since the advent of direct-printed resins and aligners, various studies have compared their properties, such as thickness, force profile, and other mechanical properties, with those of thermoformed aligners.[12-14] Among the various properties, the dimensional accuracy of the aligners that are manufactured from the 3D model and the fit of the aligner are important characteristics, which affect their effectiveness in moving teeth.[6] The dimensional accuracy of the aligner can be evaluated by one of three methods: optical scanning-based measurements, micro-computed tomography, and computer-coordinate machines.[15] Investigations by Jindal et al.[16] and Spangler et al.[17] compared the dimensional accuracy of thermoformed aligners with direct-printed aligners. Both studies found that directly printed aligners were more accurate. However, they used Dental LT material (Formlabs, Somerville, MA, USA) as the direct-printed aligner resin. Recently, graphy introduced direct-printed shape memory aligners for clinical use. Initially, TC-85 (Tera Harz, Graphy Inc, Seoul, South Korea) was available; an improved resin, TA-28 (Tera Harz, Graphy Inc, Seoul, South Korea), has now been introduced. TA-28 has improved flexural strength, flexural modulus, and superior chemical stability compared to the TC-85.[18,19] Although TA-28 and TC-85 possess several shared components and physical characteristics, there may be variations in the biomechanical qualities and performance of the aligners that need to be assessed.[18] Koenig et al.[15] compared the dimensional accuracy of direct-printed aligners manufactured using TC-85 with thermoformed aligners. However, there is limited evidence regarding the performance of TA-28 material. The primary objective of the present study was to compare the accuracy and fit of direct-printed aligners fabricated using TA-28 resin with those of thermoformed aligners.

METHODS

The study commenced following approval from the Saveetha Dental College Institutional Human Ethical Committee (approval number: SRB/SDC/ORTHO-2307/25/091, date: February, 2025). This *in vitro* observational study used a pretreatment upper-arch scan in Standard Tessellation Language (STL) format from a patient with 3.5 mm anterior crowding as a reference digital model. This file was used to plan sequential tooth movements and evaluate aligner fit and trueness in the presence of mild crowding and intact anatomy. The STL file of the arch was exported to OrthoAnalyzer (3Shape, Denmark) for planning the tooth movements. Apart from the pre-treatment model, 12 models at different stages of planning were exported as individual STL files. Three groups of aligners were fabricated on each of the 13 baseline models (n=13). The study workflow has been illustrated in Figure 1.

The sample size was calculated based on a previous study[15] using G*Power software (version 3.1, University of Dusseldorf, Dusseldorf, Germany). Based on a calculated effect size (f)

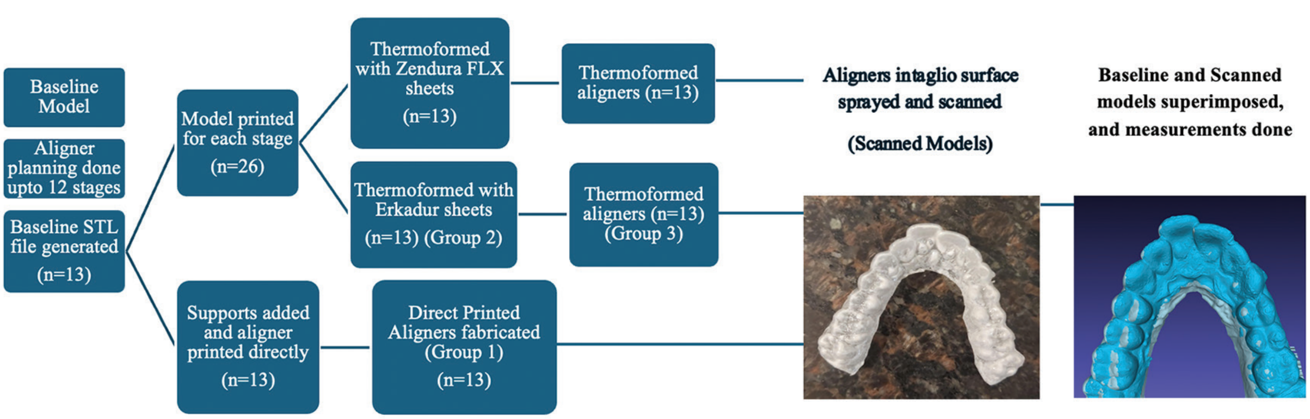

Figure 1. Study workflow.
STL, Standard Tessellation Language.

of 0.46, a significance level (α) of 0.05, and a power (1-β) of 0.90 for a one-way analysis of variance across three groups, a sample size of 13 aligners per group was required. A total of 13 models, comprising one pre-treatment stage and 12 sequential planning stages, were used to fabricate aligners. A total of 39 aligners were included in the study across three groups as follows:

Group 1: Direct-printed aligners using TA-28 resin (Tera Harz™, TA-28, Graphy Inc, Seoul, Korea); (n=13).

Group 2: Thermoformed aligners using triple-layer polyurethane (PU) sheets (Zendura FLX™, Bay Materials LLC, Fremont, CA, USA); 0.75 mm thickness; (n=13).

Group 3: Thermoformed aligners using polyethylene terephthalate glycol-modified (PET-G) sheets (Erkodur™, Erkodent Erich Kopp GmbH, Pfalzgrafenweiler, Germany); 0.75 mm thickness; (n=13).

For direct-printed aligners, additional setup and slicing were performed for each STL model using Graphy Aligner Design Studio software (Graphy Inc., Seoul, South Korea), and the models were printed with the Graphy GP-200 DLP printer (Graphy Inc., Seoul, South Korea), specifically calibrated for TA-28 resin. All aligners were printed with a uniform thickness of 0.75 mm and a gingival coverage of 1 mm. After printing, the aligners were cured under a nitrogen atmosphere using Cure M (Graphy Inc., Seoul, Korea). Excess resin and supports were carefully removed and polished.

For thermoformed aligners, the STL files of the models were exported to NextDent™ design software, where they were optimized for model printing, and then printed using a DLP 3D printer (NextDent™ 5100, version 1.1, 3D Systems Inc., the Netherlands) with NextDent® Model 2.0 resin (3D Systems Inc., the Netherlands). All models were printed with a layer thickness of 50 µm, oriented horizontally to ensure surface uniformity. Each model was post-cured in accordance with the manufacturer's guidelines using the LC-3DPrint Box (NextDent, 3D Systems Inc., Netherlands). Based on the group assignment, the respective aligner sheets were thermoformed over the models using a Biostar® pressure thermoforming unit (Scheu Dental, Germany). The sheets were heated and vacuum-formed over the printed models following a cooling protocol as advised by the respective manufacturers. The aligners were trimmed 1 mm above the gingival margin using rotary discs to simulate clinical finishing.

Assessment of Dimensional Accuracy

Aligners from all three groups were prepared for scanning by spraying their intaglio surfaces with CAD/CAM scan spray (Easy Scan, Alphadent, Korea), which rendered the aligners opaque. The aligners were then scanned using the 3Shape Trios 3™ intraoral scanner (3Shape, Denmark), producing high-resolution STL files.

The baseline models and the models obtained after scanning the aligners (scanned models) were imported into MeshLab software (version 2023.12, Italian National Research Council, Rome, Italy) for superimposition to assess the overall deviation between the models. The baseline and scanned models were superimposed using point-based gluing. The overall accuracy was recorded as root-mean-square (RMS) values. The measurements were performed in triplicate, and the mean was used for the final statistical analysis. The RMS value reflected the accuracy (trueness) of the aligners.

The fit of the aligner was evaluated by measuring the distance between the scanned and baseline models at nine designated points (Figure 2). These landmarks were selected to ensure a thorough distribution of points across anterior, posterior, occlusal, and gingival regions, thereby facilitating a multi-

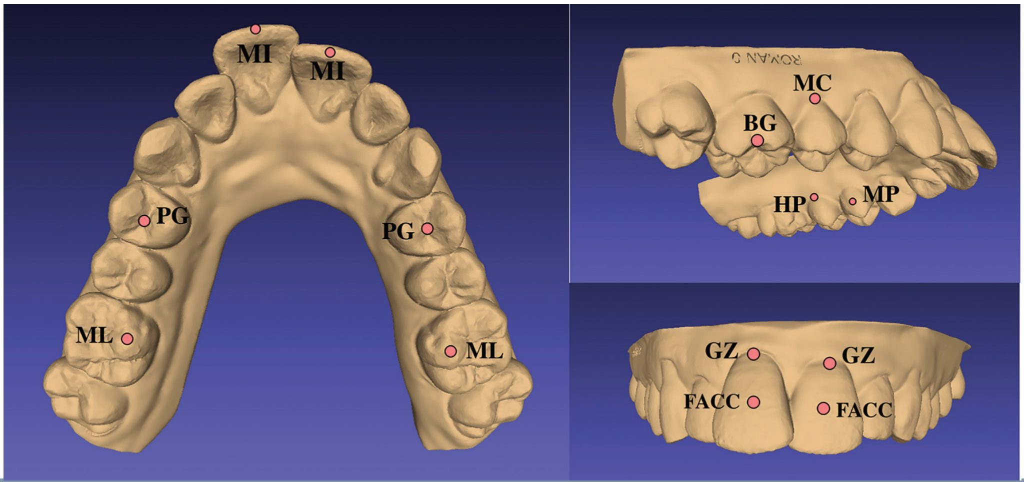

Figure 2. Nine bilateral landmarks used in the study.
MI, point on the mid-incisal edge of the central incisors; PG, mid-point on the central groove of the first pre bicuspids; ML, mesio-lingual cusp tips of the first molars; FACC, the point of the facial axis of the central incisor that separates the gingival and occlusal halves; MP, mid, point on the palatal surface of the first bicuspids; BG, a point on the buccal groove of the first molars; GZ, gingival zenith of the central incisor; HP, highest point on the palate-gingival margin of the second bicuspid; MC, highest point on the bucco-gingival margin of the second bicuspid; SD, standard deviation.

surface evaluation of the aligner's anatomical fit. Each deviation value (in mm) was recorded separately for the left and right sides, and the mean of two sides was used for statistical analysis. The methodology and landmarks for deviation analysis were adapted from the protocol described by Koenig et al.[15]

Statistical Analysis

Descriptive statistics (mean and standard deviation) were calculated for all parameters. Normality of the data was assessed using the Shapiro-Wilk test. The overall accuracy (RMS value) and deviation values at each landmark among the three groups were compared using the Kruskal-Wallis test, followed by intergroup comparisons using the Dunn-Bonferroni post-hoc test. To assess reliability, all measurements from 10 randomly selected samples were repeated after 3 weeks by the same operator. Two additional operators repeated the measurements after 3 weeks. Intra- and inter-rater reliabilities for both overall and landmark-based deviation values were assessed using the intraclass correlation coefficient (ICC). Statistical significance was set at a p-value less than or equal to 0.05.

RESULTS

The reliability of measurements was high, with intra-rater ICC values ranging from 0.820 to 0.932 for all parameters. The inter-rater ICC values ranged from 0.75 to 0.81, indicating good agreement across all parameters.

Based on the Shapiro-Wilk test, the data were not normally distributed; therefore, a non-parametric test was performed. The overall mean deviation, expressed as RMS values, was lowest in Group 1 (0.2169±0.0312 mm), followed by Group 2 (0.3046±0.031 mm) and Group 3 (0.3292±0.024 mm). Pairwise comparisons revealed significant differences between Group 1 and Group 2 (p<0.001) and between Group 1 and Group 3 (p<0.001); the difference between Groups 2 and 3 was not significant (p=0.489) (Table 1).

The deviation values at the nine anatomical landmarks were consistently the smallest relative to the baseline models for Group 1. The differences among the three groups were statistically significant at all landmarks (p<0.001) (Table 2). However, pairwise comparisons of the landmark-based deviations revealed that across all nine landmarks, the deviation in Group 1 was significantly lower than in Groups 2 and 3 (p<0.001). When Group 2 and Group 3 were compared, significant differences were observed at most landmarks, with Group 3 exhibiting slightly greater deviation than Group 2 (Figure 3).

Table 1. Comparison of the root mean square (RMS) values between the groups

Parameter assessed	Groups (mean ± standard deviation)⁺			p-value
	Group 1	Group 2	Group 3	
RMS value	0.2169±0.0312	0.3292±0.024	0.3046±0.031	<0.001*
Inter-group comparison^				
	Group 1-Group 3	Group 1-Group 2	Group 2-Group 3	
Adjusted p-value	<0.001*	<0.001*	0.489	

⁺Kruskal-Wallis test.
^Pairwise comparison using Dunn-Bonferroni test.
*Indicates statistical significance (p<0.05).
RMS, root-mean-square.

Table 2. Comparison of the mean deviation values at each landmark between the groups

Landmarks	Deviation values Mean ± standard deviation (SD)⁺			p-value
	Group 1	Group 2	Group 3	
MI	0.1995±0.0035	0.218±0.0033	0.2347±0.0034	<0.001*
PG	0.1894±0.001	0.1923±0.001	0.2148±0.0012	<0.001*
ML	0.4261±0.0008	0.4695±0.0011	0.5042±0.0011	<0.001*
FACC	0.4705±0.0005	0.5005±0.0005	0.5081±0.0008	<0.001*
MP	0.286±0.0032	0.3109±0.0038	0.329±0.0035	<0.001*
BG	0.4542±0.003	0.4921±0.0038	0.5208±0.0058	<0.001*
GZ	0.2475±0.0145	0.3043±0.0401	0.3954±0.0537	<0.001*
HP	0.15±0.0019	0.1577±0.0027	0.1671±0.0039	<0.001*
MC	0.3497±0.0032	0.3755±0.0039	0.4009±0.0035	<0.001*

Table 2. Continued

Landmarks	Deviation values Mean ± standard deviation (SD)+			p-value
	Group 1	Group 2	Group 3	
Pairwise comparison (Adj. p-values)^				
	Group 1-Group 3	Group 1-Group 2	Group 2- Group 3	
MI	<0.001*	0.011*	0.011*	
PG	<0.001*	0.015*	0.009*	
ML	<0.001*	0.01*	0.01*	
FACC	<0.001*	0.003*	0.01*	
MP	<0.001*	0.004*	0.011*	
BG	<0.001*	0.004*	0.004*	
GZ	<0.001*	0.028*	0.013*	
HP	<0.001*	0.013*	0.011*	
MC	<0.001*	0.011*	0.004*	

+Kruskal-Wallis test.
^Pairwise comparison using Dunn-Bonferroni test.
*Indicates statistical significance (p<0.05).
MI, point on the mid-incisal edge of the central incisors; PG, mid-point on the central groove of the first pre bicuspids; ML, mesio-lingual cusp tips of the first molars; FACC, the point of the facial axis of the central incisor that separates the gingival and occlusal halves; MP, mid-point on the palatal surface of the first bicuspids; BG, a point on the buccal groove of the first molars; GZ, gingival zenith of the central incisor; HP, highest point on the palate-gingival margin of the second bicuspid; MC, highest point on the bucco-gingival margin of the second bicuspid.

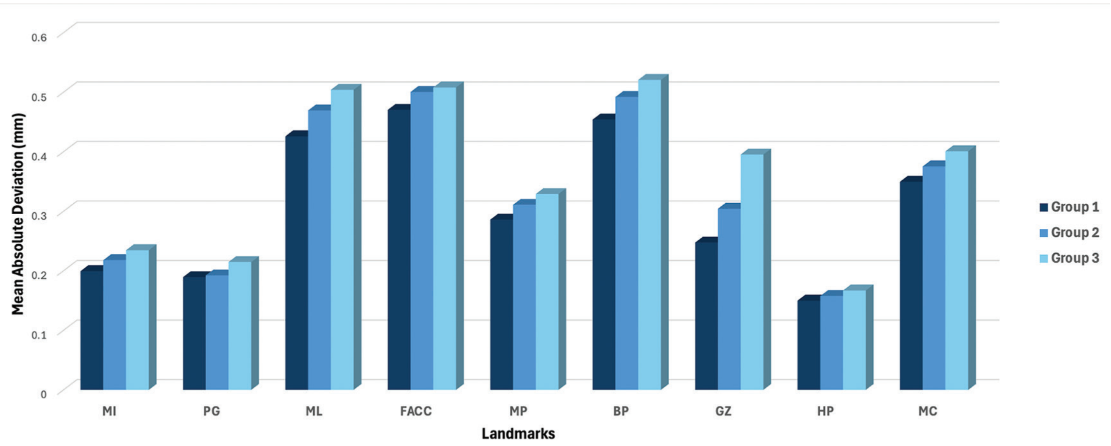

Figure 3. Graph depicting the comparison of the mean deviation of the aligners across Groups 1-3 in the nine landmarks assessed.
MI, point on the mid-incisal edge of the central incisors; PG, mid-point on the central groove of the first pre bicuspids; ML, mesio-lingual cusp tips of the first molars; FACC, the point of the facial axis of the central incisor that separates the gingival and occlusal halves; MP, mid, point on the palatal surface of the first bicuspids; GZ, gingival zenith of the central incisor; HP, highest point on the palate-gingival margin of the second bicuspid; MC, highest point on the bucco-gingival margin of the second bicuspid.

DISCUSSION

The present study used MeshLab software to assess the accuracy of aligners by applying point-based gluing for superimposition. MeshLab is utilized for processing STL files and superimposition; it is free, open-source software.[20] Koenig et al.[15] and Spangler et al.[17] utilized Geomagic Control X software (3D Systems, Morrisville, NC, USA) and MeshMixer (Autodesk, San Rafael, CA, USA) to process and assess deviations across the samples. The best fit alignment used in Geomagic software utilized the rugae area as a landmark for superimposition and was found to be more accurate than using landmarks on teeth for model alignment.[21] The use of this software provides comprehensive three-dimensional analysis but requires careful consideration of scanning spray thickness, which accounts for approximately 0.01899 mm and 0.0803 mm and potential alignment errors due to the type of superimposition.[15] Jindal et al.[16] employed direct measurement of tooth heights by multiple observers, while Cole et al.[22] used engineering software to measure distances at specific reference points. Differences in the measurement protocol could introduce errors and may account for for variations in the reported outcomes and the slight deviations observed in the present study. The study protocol and methodology closely followed those of Koenig et al.[15] to ensure comparability with the newer direct-printed aligner material TA-28, which was not included in their original investigation.

The result of this study indicated that direct-printed aligners exhibited greater dimensional accuracy and better fit than thermoformed aligners. The overall deviation of the aligners (RMS value) from the baseline STL models was smallest for direct-printed aligners (Group 1), and this difference was significant compared with thermoformed aligners. Previous studies have found that about 0.15-0.25 mm of space between the tooth and aligner is acceptable.[17] However, in this study, thermoformed aligners showed deviations of more than 0.25 mm, unlike the direct-printed aligners. The study also assessed deviations from the baseline models at nine specific bilateral landmarks to evaluate aligner fit. The landmarks were selected to represent all surfaces of the aligners. Aligners produced by direct printing showed the lowest deviations at all nine reference points evaluated in this study; their deviation values were significantly lower than those of aligners produced by thermoforming.

Koenig et al.[15] reported RMS values of 0.188±0.074 mm for Zendura FLX™, 0.209±0.094 mm for Essix ACE™, and 0.140±0.020 mm for direct-printed aligners manufactured using Tera Harz™ TC-85DAP resin. The present study's RMS values were slightly higher than theirs; however, the direct-printed aligners showed significantly better overall trueness than thermoformed alternatives. They also observed the lowest deviations at all nine assessed landmarks, with statistically significant differences at six of the nine bilateral landmarks compared with thermoformed aligners. Another study by Jindal et al.[16] compared geometrical and mechanical properties of thermoformed Duran aligners with 3D-printed aligners fabricated using Dental LT Clear resin. Their geometric analysis revealed that 3D-printed aligners were more accurate, with an average absolute difference of 0.21 mm compared with 0.37 mm for thermoformed aligners, which supports the present study's findings of superior dimensional accuracy with direct printing. Similarly, Spangler et al.[17] compared Dental LT clear resin with vacuum-formed aligners (Invisacryl Ultra, Thermal Forming Material, Great Lakes Dental Technologies, Tonawanda, NY) and found that the direct-printed aligners exhibited better trueness than the vacuum-formed aligners. However, Cole et al.[22] reported conflicting results when evaluating 3D-printed retainers fabricated with Dental LT Clear resin. In their study, vacuum-formed retainers exhibited the smallest deviation from reference models (0.10-0.20 mm), whereas 3D-printed retainers exhibited the largest deviation (0.10-0.40 mm). The differences between the findings between Cole et al.[22] and other studies may be due to differences in resin materials and post-curing protocols. They acknowledged that all retainers, including the 3D-printed ones, yielded measurements within the 0.50 mm threshold generally considered clinically acceptable for orthodontic appliances. For direct-printed aligners, resin selection is critical. The present study and the study by Koenig et al.[15] used Tera Harz resins (TA 28 and TC-85 DAP, respectively), which were specifically formulated for aligner printing, and demonstrated superior dimensional accuracy. In contrast, Jindal et al.[16] and Cole et al.[22] used Dental LT Clear resin, which was originally intended for hard splints and retainers. This variability highlights the necessity of using resins specifically designed for aligner applications, rather than materials intended for other dental uses.

Among thermoformed materials, the present study found that PU-based aligners (Zendura FLX) were more accurate than PET-G aligners (Erkodur); however, the differences were not statistically significant. This aligns with the findings of Koenig et al.,[15] who reported lower RMS values and more consistent performance with Zendura FLX compared to Essix ACE. The favourable performance of PU materials may be attributed to their superior thermoforming characteristics and adaptability.[23]

Strengths of the study include using the same intraoral scanner for all groups. The present study set the thickness of both thermoformed and direct-printed aligners to 0.75 mm. However, previous studies have suggested that although thickness can be controlled in direct 3D printing, the 3D printing workflow did not accurately replicate the designed thicknesses, and this discrepancy may have an impact on the fit of the aligner.[24] The study by Shirey et al.[13] found that thermoformed aligners measured thinner after thermoforming, while direct-printed aligners measured thicker. Direct printing of aligners often resulted in an increase in wall thickness of approximately 0.2 mm.[24]

Study Limitations

Although the the present study used uniform thickness for all groups, the thickness of the manufactured aligners was not confirmed post-fabrication, and their relationship with dimensional accuracy and fit was not assessed. This limitation should be investigated in future research. The dimensional accuracy and the properties of the aligners can vary with changes in materials used, printing technology, printing orientation, post-processing techniques, and the software used for assessment.[25,26] Hence, the present study sheds light on only one aspect of these collective factors. Moreover, dimensional accuracy alone is not a sufficient indicator of the aligner's performance. Consequently, more clinical studies using standardized manufacturing processes must be conducted to evaluate the clinical predictability and translation of tooth movements between direct-printed and thermoformed aligners, in order to validate the results of *in vitro* studies. Furthermore, given advances in direct-printed aligner systems, a comparison of the various resins available on the market could facilitate informed clinical decision-making. Direct-printed aligners provide a more accurate alternative to thermoformed aligners, minimizing the manufacturing steps and reducing the need to discard millions of unrecyclable dental models, which adds to the environmental burden.[27]

CONCLUSION

In this *in vitro* study, direct-printed aligners fabricated using TA-28 resin demonstrated significantly greater dimensional accuracy and improved fit compared with thermoformed aligners made from PU (Zendura FLX) and PET-G (Erkodur). Direct-printed aligners demonstrated significantly reduced deviations across all nine anatomical landmarks assessed. Among thermoformed materials, PU-based aligners showed marginally better accuracy than PET-G aligners. The enhanced dimensional accuracy and consistent fit demonstrated by directly printed aligners suggest potential advantages for clinical orthodontic practice.

Ethics

Ethics Committee Approval: The study was approval from the Saveetha Dental College Institutional Human Ethical Committee (approval number: SRB/SDC/ORTHO-2307/25/091, date: February, 2025).

Informed Consent: Written consent was obtained from the patient for using digital model in the study.

Footnotes

Author Contributions: Concept - S.N.; Design - N.F., S.N.; Data Collection and/or Processing - N.F.; Analysis and/or Interpretation - N.F., S.N.; Literature Search - N.F., S.N.; Writing - N.F., S.N.

Conflict of Interest: The authors do not have any conflict of interest to disclose.

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Original Article

Comparison of Premaxillary Dimensions in Patients with Palatally and Buccally Impacted Maxillary Canines and Those with Normally Erupted Canines: A Retrospective Cone-Beam Computed Tomography Study

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Main Points

- Patients with impacted maxillary canines exhibit increased premaxillary height, depth, and volume compared to those with normally erupted canines.
- Premaxillary width does not differ significantly between impacted and non-impacted groups.
- Palatal canine impaction is associated with a significantly greater premaxillary volume than in buccal impaction.

ABSTRACT

Objective: Research into the etiology of maxillary canine impaction (MCI) has focused primarily on the transverse dimensions of the maxilla in the premolar and molar regions. The aim of this study was to evaluate and compare premaxillary width, height, depth, and volume -assessed using cone-beam computed tomography (CBCT)- among individuals with palatal MCI, buccal MCI, and normally erupted maxillary canines.

Methods: This retrospective study utilized CBCT records of patients with MCI. A total of 45 subjects were divided into three groups of 15 subjects each. Group I (palatal canine impaction), Group II (buccal canine impaction), and Group III (control group of normally erupted canines). Premaxillary width, height, depth, and volume were measured in axial, coronal, and sagittal planes using Horos software. All measurements were performed by a single calibrated examiner. One-way ANOVA with Tukey post-hoc analysis was applied; statistical significance was set at $p<0.05$.

Results: Premaxillary height, depth, and volume were significantly greater in both palatal canine impaction (Group I) and buccal canine impaction (Group II) groups compared to controls (Group III). The increase was greatest in Group I, and this difference among the three groups was statistically significant ($p=0.04$ for height, 0.0005 for depth, and 0.04 for volume). Premaxillary width did not differ significantly among groups ($p=0.38$). Post-hoc analysis revealed that premaxillary depth was significantly greater in both palatal and buccal impaction groups than in controls ($p=0.021$ and 0.002, respectively), while premaxillary volume was significantly greater in the palatal than in the buccal canine impaction group ($p=0.03$).

Conclusion: The findings of this study suggest that three-dimensional premaxillary morphology, as assessed by CBCT -particularly increased depth and volume- may be associated with MCI, with a more pronounced effect in palatal impaction. Premaxillary width did not demonstrate a significant association. These results indicate that localized anterior maxillary skeletal characteristics, rather than transverse maxillary deficiency alone, may influence the eruptive pathway of maxillary canines. These findings represent associations and do not establish causality. Prospective studies with larger sample sizes are warranted to validate these findings and to explore their clinical implications for early orthodontic intervention.

Keywords: Palatal canine impaction, premaxilla, impacted canines, cone-beam computed tomography, craniofacial complex, maxillary dimension

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INTRODUCTION

Maxillary canines have the longest developmental period and undergo a complex process from their origin to achieving complete occlusion.[1] Following impacted third molars, impaction of the permanent maxillary canine is the second most common type of tooth impaction.[2] Numerous factors can contribute to this condition, including genetics,[3] discrepancies in arch length,[4] a lengthy eruption path,[5] and alterations in the surrounding environment caused by hard tissue structures, soft tissue lesions, or developmental anomalies such as the reduced length or absence of the lateral incisor.[6]

Buccal canine impaction is generally associated with insufficient arch length.[7] However, the etiology of palatal canine impaction remain largely unknown. Two prominent theories have been proposed regarding its etiology: the guidance theory and the genetic theory.[8] The guidance theory posits that maxillary canines erupt following the roots of the lateral incisors, which serve as guides. If the lateral incisor roots are missing, canines may not erupt properly and may become impacted.[9] Conversely, the genetic theory suggests that hereditary factors are involved in palatal canine impaction.[10] Additionally, researchers have investigated the connection between maxillary morphology and the frequency of palatal canine impaction.[11]

Previous studies have suggested that craniofacial structure may be indicative of permanent canine impaction. This could be associated with the fact that the maxilla and palate originate from the neural crest cells, as do the dental epithelial cells. Additionally, variations in the expression of genes such as *MSX*, *PAX9*, and members of the *HOX* gene family seem to influence the development of both the midface and the teeth.[12]

A canine tooth might be positioned palatally if there is additional space in the maxillary bone, which can result from overdevelopment at the base of the maxilla, the absence of lateral incisors, or the stimulated eruption of adjacent teeth. In such cases, the canine becomes palatally impacted.[13] Abnormal development of the maxillary-premaxillary suture can similarly alter the eruption trajectory of the maxillary canine.[14]

Previous research has analysed the lateral cephalograms of patients with palatal canine impaction and found that these patients often have a longer premaxilla.[15]

The advent of cone-beam computed tomography (CBCT) has enabled more accurate and objective three-dimensional assessment of craniofacial structures. Diagnostic tools for detecting canine impaction that utilise CBCT, including the KPG index[16] and Easy Box[17], have been developed for effective diagnosis and treatment planning to determine the position and treatment difficulty. Prior literature has focused on the transverse dimension of the maxilla in the premolar and molar region in maxillary canine impaction (MCI).[18-21] As limited studies have specifically evaluated the three-dimensional morphology of the premaxilla using CBCT in patients with impacted maxillary canines previously, the present study aimed to assess and compare the dimensions of the premaxilla in individuals with palatally and buccally impacted, and normally erupted maxillary canines. It was hypothesised that patients with palatally impacted canines would exhibit greater premaxillary dimensions compared to patients with buccally impacted canines and to non-impacted controls, suggesting a potential aetiological role of localized premaxillary morphology in palatal canine impaction.

METHODS

Ethical Approval

This retrospective observational study was approved by the Sri Ramachandra Institute of Higher Education and Research Ethics Committee for Student Projects (approval no: CSP/25/JAN/155/26, date: 27.03.2025). The research was carried out in accordance with the principles outlined in the Declaration of Helsinki (1964) and its subsequent revisions, current ethical standards, and the ALARA principle.

Sample

CBCT scans of the maxilla were collected from the archives of the Department of Orthodontics according to the following inclusion and exclusion criteria.

Inclusion Criteria

1. Subjects with a full complement of permanent dentition (except the impacted maxillary canine in the impaction groups) with or without third molars are visible on CBCT images.
2. No sex restrictions were applied.
3. Patients with retained/exfoliated deciduous teeth whose permanent successors had not yet erupted.
4. For the impaction groups, maxillary canines were classified as palatally or buccally impacted based on their three-dimensional position relative to the dental arch and alveolar process on CBCT images.
5. The control group consisted of patients with normally erupted maxillary canines and no history of dental impaction, who were matched for age and sex.

Exclusion Criteria

1. Low-quality radiographs.
2. Patients undergoing orthodontic treatment.
3. Individuals younger than 13 years of age.
4. Patients with cleft palate and any other congenital anomaly.
5. Cases in which impaction was attributable to local or secondary causes, such as odontomas, cysts, supernumerary teeth, or tumours
6. Patients with a history of traumatic dental injuries and any other factor affecting the natural path of eruption.

The sample size was calculated based on the study by Servais et al.[22] Assuming a power of 80%, a total sample size of 45 subjects was determined to be sufficient to detect the expected difference between groups.

Following institutional ethical approval, CBCT records obtained between June 2021 and January 2025 were retrospectively reviewed. Patient records, including medical and dental histories, were examined consecutively to identify individuals with impacted maxillary canines. Age- and sex-matched controls without dental impaction (excluding third molars) were selected from the same database.

A total of 45 subjects (24 females and 21 males; age range, 17-30 years) met the inclusion criteria and were allocated to three groups: palatal canine impaction (n=15), buccal canine impaction (n=15), and control (n=15). In the palatal impaction group, 12 subjects had Class I malocclusion, 2 had Class II malocclusion, and 1 had Class III malocclusion. In the buccal impaction group, 13 subjects had Class I malocclusion, 1 had Class II malocclusion, and 1 had Class III malocclusion. All subjects in the control group exhibited Class I malocclusion.

The presence of palatal or buccal canine impaction in the subjects was verified using CBCT. If the diagnosis remained unclear, the senior author reviewed the records; if no agreement was reached, the individual was excluded from the study.

Each CBCT scan included the complete maxilla and mandible, with a field of view of 155x95 mm^2 and a voxel size of 0.25x0.25x0.25 mm. The DICOM datasets were imported and analysed using Horos software (Horos project, Geneva, Switzerland) on a Macintosh computer (MacBook Pro, Apple Computer, Inc., Cupertino, California). Quantifications were derived using the digital ruler feature in the multisector reconstruction module of the Horos software. The slice thickness was 5 mm. The segmentation of the region of interest (ROI) was performed using the closed polygon tool in Horos software. The ROI was manually delineated on each axial slice according to the cortical boundaries of the premaxilla. No fixed gray-value or Hounsfield unit threshold was applied because of the known variability of CBCT gray values. Instead, cortical boundaries were visually identified on each slice to ensure consistent anatomical segmentation while excluding adjacent anatomical structures.

The segmented ROIs from all axial slices were aggregated by the software to calculate the total premaxillary volume using slice-by-slice planimetric integration. All measurements were performed using a standardised protocol with a consistent inter-slice interval across all subjects.

Measurements

Premaxilla Width

Premaxillary width was measured as the distance between the alveolar bone at the distal surfaces of the right and left maxillary lateral incisors at the midpoint between the labial and palatal cortical plates on the mid-axial section. The mid-axial section was taken between the inferior border of the palate and the crestal bone separating the two maxillary central incisors (Figure 1).

Premaxillary Height

On the midsagittal section, a horizontal reference line connecting the anterior nasal spine (ANS) and posterior nasal spine and a perpendicular line from the alveolar crest of the visible maxillary central incisor were drawn. Premaxillary height was defined as the distance between the alveolar crest and the point of intersection of the horizontal and the vertical lines (Figure 2).

Premaxillary Depth

The premaxillary depth was measured as the distance from the external vestibular cortex to the internal lingual cortex at three vertical reference points on the external vestibular cortex: (a) 1 mm below the cementoenamel junction, (b) two-thirds of the root level, and (c) at the level of the ANS, oriented perpendicular to the long axis of the central incisor in the midsagittal section (Figure 3).

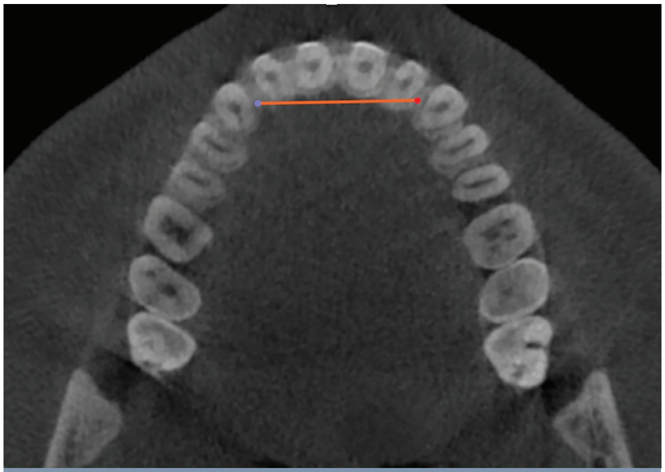

Figure 1. Measurement of the width of the premaxilla.

Figure 2. Measurement of the height of the premaxilla.

Premaxillary Volume

The ROI was defined by the following boundaries: laterally, the cortical bone distal to the maxillary lateral incisors bilaterally; and anteroposteriorly, from the ANS to a level corresponding to two-thirds of the length of the nasopalatine canal. A closed polygon tool was used to manually delineate the ROI on consecutive short axial slices, followed by manual planimetry to calculate volume. For each slice, the boundary of the depicted area was traced by completing a closed polygon, ensuring the final point coincided with the initial point. After delineation of all slices encompassing the full extent of the target region, volumetric analysis was performed to obtain the total bone volume (Figure 4).

All measurements for each variable were repeated by the same operator on 10 randomly selected samples after 20 days, and the intraclass correlation coefficient (ICC) was calculated to assess the reliability of the method.

Figure 3. Measurement of the depth of the premaxilla.

Statistical Analysis

All statistical analyses were performed using R Software (version 4.2.2). Intra-examiner reliability was assessed using the ICC. A single examiner was used to eliminate inter-examiner variability. The Shapiro-Wilk test was performed to assess whether the data were normally distributed. Differences among the three groups were assessed using one-way analysis of variance, followed by Tukey's honestly significant difference post-hoc test for pairwise comparisons. Statistical significance was set at $p<0.05$. In addition to p-values, Cohen's d was calculated for pairwise comparisons to assess the magnitude of differences between groups. Effect sizes were interpreted as small (0.2), moderate (0.5), and large (≥0.8).

RESULTS

Intra-examiner reliability was high for all parameters, with ICC values ranging from 0.989 to 0.998 (Table 1). Descriptive data on canine impaction type and premaxillary dimensions are presented in Table 2. Premaxillary height, depth, and volume were greater in both the palatal and buccal canine impaction groups than in controls (Table 2). The increase was greatest in the palatal impaction group and was statistically significant among the three groups (p=0.04 for height, p=0.0005 for depth, and p=0.04 for volume). There was no significant difference in premaxilla width among the three groups (p=0.38) (Figure 5, Table 2).

Table 1. Intra-examiner reliability

Premaxilla dimension	ICC	95% CI
Height	0.996	(0.980, 0.996)
Width	0.996	(0.994, 0.999)
Depth	0.989	(0.957, 0.993)
Volume	0.998	(0.996, 0.999)

ICC, intraclass correlation coefficient; CI: confidence interval.

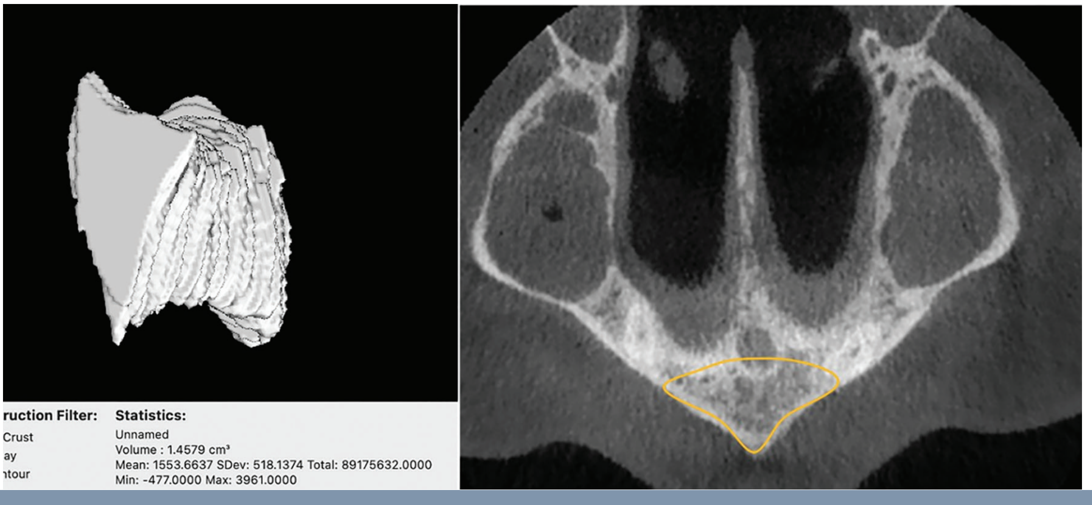

Figure 4. Measurement of the volume of the premaxilla.

Post-hoc analyses demonstrated premaxillary height was significantly greater in the palatal impaction group than in the control group (p=0.03) (Table 3, Figure 6). Similarly, premaxillary depth was significantly greater in the palatal impaction group than in the control group (p=0.02) (Table 3, Figure 7). Premaxillary depth was also significantly greater in the buccal impaction group compared to controls (p=0.002). Premaxillary volume was significantly greater in the palatal impaction group than in the buccal canine impaction group (p=0.03) (Table 3, Figure 8).

Effect size analysis revealed large effects for premaxillary depth and volume, particularly between palatal impaction and control groups (Cohen's d=0.78-1.08). Premaxillary height showed a large effect size between the palatal impaction and control groups (d=1.01), whereas premaxillary width showed only small effect sizes across comparisons (Table 3).

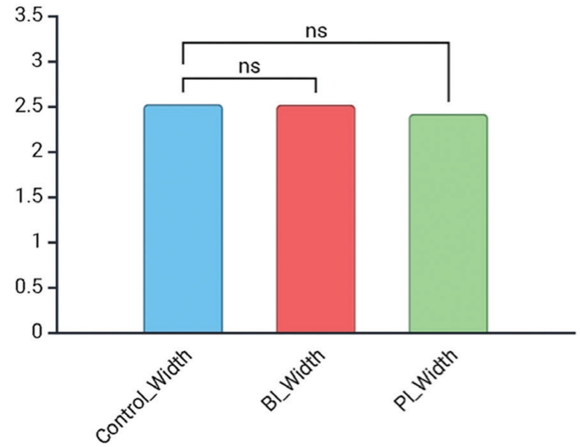

Figure 5. Post-hoc Tukey's multiple comparison test for width of the premaxilla.

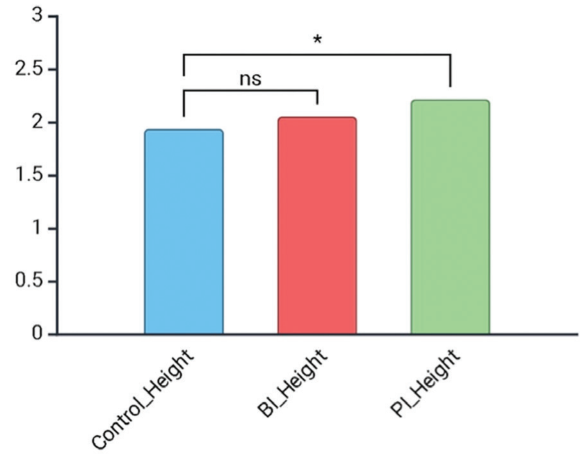

Figure 6. Post-hoc Tukey's multiple comparison test for height of the premaxilla.

Table 2. One-way ANOVA for comparison of mean premaxillary dimensions between three groups

Premaxilla dimension	Group I P		Group II B		Group III C		
	Mean	SD	Mean	SD	Mean	SD	p-value
Height	2.22 cm	0.29	2.05 cm	0.31	1.94	0.26	0.04*
Width	2.42 cm	0.24	2.52 cm	0.26	2.53	0.19	0.38
Depth	4.05 cm	0.70	3.99 cm	0.46	3.47	0.22	0.0005*
Volume	2.24 cm^3	0.72	1.68 cm^3	0.32	1.78 cm^3	0.49	0.04*

*The significance level was set at p<0.05.
ANOVA, analysis of variance; SD, standard deviation.

Table 3. Post-hoc comparison of mean premaxillary dimensions between groups

Measurement	Comparison	p-value	Mean difference	95% CI of difference	Cohen's d
Height	Control vs. Buccal	0.53	0.116	0.377-0.145	0.39
	Control vs. Palatal	0.03	0.278	0.539-0.016	1.01*
	Buccal vs. Palatal	0.29	0.162	0.423-0.099	0.58
Width	Control vs. Buccal	0.99	0.0005	0.203-0.215	0.18
	Control vs. Palatal	0.43	0.107	0.102-0.319	0.22
	Buccal vs. Palatal	0.47	0.101	0.108-0.310	0.09
Depth	Control vs. Buccal	0.002	0.516	0.868-0.169	0.97*
	Control vs. Palatal	0.021	0.575	1.077-0.075	1.08*
	Buccal vs. Palatal	0.989	0.060	0.618-0.497	0.10
Volume	Control vs. Buccal	0.889	0.098	0.292-0.488	0.25
	Control vs. Palatal	0.146	0.46	1.023-0.116	0.78
	Buccal vs. Palatal	0.038	0.558	1.090-0.025	1.01*

*Cohen's d values were interpreted as small (0.2), moderate (0.5), and large (0.8). The significance level was set at p<0.05.
CI, confidence interval.

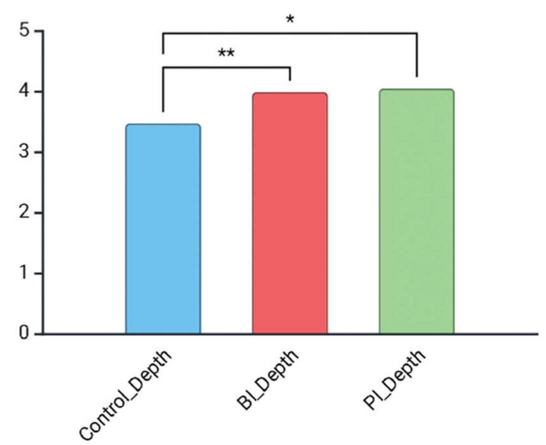

Figure 7. Post-hoc Tukey's multiple comparison test for depth of the premaxilla.

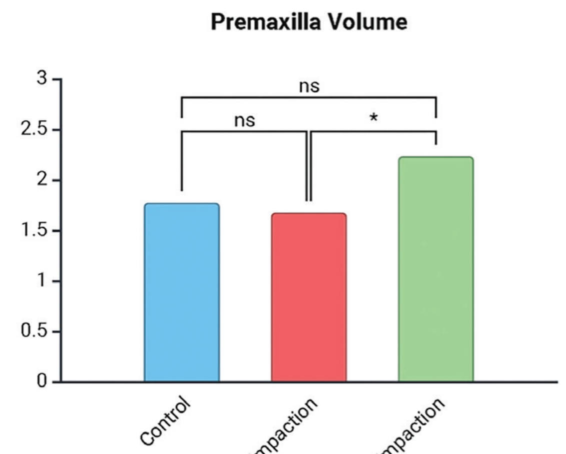

Figure 8. Post-hoc Tukey's multiple comparison test for volume of the premaxilla.

DISCUSSION

Historically, the etiology of palatal canine impaction has been attributed to genetic factors, particularly mutations involving the *MSX1* and *PAX9* genes, or to inadequate eruptive guidance caused by morphological alterations of the maxillary lateral incisor.[9,23,24] Although premaxillary dimensions have been proposed as a potential etiological factor, this region remains relatively unexplored in orthodontic literature. The present study addressed this gap by comparing premaxillary dimensions in patients with palatal canine impaction, buccal canine impaction, and normally erupted canines, and it demonstrated distinct three-dimensional morphological variations, particularly associated with palatal impaction.

Previous studies have largely focused on transverse maxillary dimensions and their relationship with palatal canine impaction, with conflicting results. Alshalawi et al.[12] reported reduced maxillary arch width in patients with palatally displaced canines, whereas Hong et al.[6] found no association with transverse width and instead emphasized lateral incisor morphology. Several studies have similarly reported no significant differences in mesiodistal tooth size, arch length-tooth size discrepancy, basal maxillary width, or arch form between the impaction and control groups.[25-31] In contrast, Mehta et al.[32] suggested that increased palatal depth, combined with reduced maxillary incisor width, may predispose to palatal impaction. Mucedero et al.[33] reported that individuals with palatally displaced permanent canines did not exhibit maxillary transverse constriction or significant variation in palatal vault morphology. While Kim et al.[8] reported a deeper palatal vault in palatal compared with buccal canine impaction.

Notably, most previous studies evaluated palatal morphology distal to the canine region. Given the close developmental and eruptive relationship between the maxillary canine and lateral incisor, assessment of the premaxilla is clinically relevant. In the present study, premaxillary width did not differ significantly among groups. However, the premaxillary depth and height were greater in both the palatal and buccal impaction groups compared with controls, although no significant differences were observed between the palatal and buccal impaction groups. These findings partially contrast with those of Athanasiou et al.,[15] who reported a significant increase in sagittal premaxillary dimension; however, that study relied on lateral cephalograms and did not evaluate three-dimensional morphology.

Although increases in premaxillary depth and height did not reach statistical significance in all pairwise comparisons, these changes may nonetheless have clinical implications. Even modest increases in sagittal or vertical dimensions can influence the spatial orientation of the developing canine, potentially altering its eruptive pathway by increasing palatal bone resistance or reducing the effectiveness of lateral incisor guidance. Such morphological variations may also impact surgical exposure, orthodontic traction mechanics, and anchorage planning in clinically complex cases.

A key finding of the present study was that premaxillary volume was significantly greater in palatal than in buccal canine impaction. This increase likely reflects the combined effect of increased depth and height, suggesting that localized three-dimensional skeletal morphology of the premaxilla, rather than generalized space deficiency, may play a more prominent role in palatal canine impaction. The absence of significant differences in premaxillary width further supports the notion that sagittal and vertical dimensions are more influential than transverse dimensions in the etiology of palatal impaction.

From a biomechanical perspective, increased premaxillary volume,may influence the eruption trajectory of the maxillary canine by altering the spatial relationships and resistance patterns within the anterior maxilla. Increased premaxillary depth may position the developing canine germ palatally relative to the dental arch, while increased vertical height can modify the eruption vector by increasing the distance the canine must traverse before reaching the occlusal plane. These morphological changes may reduce the effectiveness of lateral incisor guidance, as described by guidance theory, thereby predisposing the canine to palatal deviation during eruption. Furthermore, increased osseous volume within the premaxillary region may create greater resistance along the labial eruption pathway, further favoring palatal deviation. Although the present findings do not establish a direct causal relationship, they suggest that premaxillary morphology may act as a contributing biomechanical factor influencing the direction of canine eruption.

These factors may compromise the guidance mechanism described by Becker et al.,[9] predisposing the canine to palatal displacement. Recent CBCT-based studies support this interpretation. Firincioglulari et al.[34] demonstrated greater skeletal variation in palatal compared with buccal impactions. Likewise, the studies of Gudelevičiūtė et al.[35] and Sharhan et al.[36] identified significant anterior maxillary skeletal differences between impacted and non-impacted canines. Collectively, these findings reinforce the role of localised premaxillary morphology in palatal canine impaction.

The present findings support the hypothesis that increased premaxillary depth, height, and volume may contribute to an altered eruptive direction of the maxillary canine. Experimental evidence suggests that mutations in genes such as *MSX1* and *PAX9*, which are associated with palatal canine impaction, may also influence anterior maxillary development, particularly in the anteroposterior dimension.[24] Future studies integrating three-dimensional skeletal analysis with genetic and longitudinal eruption data are needed to clarify causal relationships.

Clinical Implications

Although impacted maxillary canines are conventionally evaluated based on three-dimensional position, proximity to adjacent roots, and available arch space, the findings of the present study suggest that premaxillary morphology may represent an additional anatomical factor, particularly in cases of palatal impaction. Increased premaxillary depth and volume may alter the spatial relationship between the lateral incisor and canine tooth germ, potentially compromising eruptive guidance.[7,9]

This observation is supported by recent CBCT-based studies that have reported significant anterior maxillary skeletal variations in patients with impacted canines.[34-36]

Premaxillary dimensions assessed on CBCT should therefore be regarded as adjunctive indicators of risk rather than standalone predictive parameters. Advanced CBCT-based indices such as the KPG index[16] and Easy Box[17] have further highlighted the importance of three-dimensional evaluation in assessing canine impaction and treatment complexity.

Although specific threshold values cannot be established from the present data because of the limited sample size, patients exhibiting increased anterior maxillary volume and sagittal depth may benefit from closer radiographic monitoring and early interceptive measures during the mixed dentition phase.

It should be emphasized that the morphological differences identified in this study are associative rather than definitively causal. Longitudinal studies incorporating skeletal morphology, eruption timing, and genetic markers are required to establish clinically applicable predictive models.

Study Limitations

The relatively small sample size limits the generalisability of the findings; therefore, the results should be interpreted with caution and regarded as preliminary, despite adequate statistical power reported in prior literature. Volumetric measurements were obtained by manual ROI delineation on axial CBCT slices with a 5-mm inter-slice interval, which may have introduced partial-volume effects. However, identical imaging and measurement protocols were applied across all groups, permitting valid intergroup comparisons. Impacted canines were classified solely as buccally or palatally impacted without further classification according to severity parameters, as the primary objective was to assess premaxillary morphology rather than impaction complexity. Future studies incorporating larger samples, longitudinal designs, genetic data, and three-dimensional severity indices are warranted to further elucidate these relationships.

CONCLUSION

Both buccal and palatal canine impaction groups showed increased premaxillary depth compared with controls. In addition, premaxillary height and volume were increased in the palatal impaction group, with premaxillary volume being significantly greater than that observed in the buccal impaction group.

The findings suggest that localized three-dimensional variations in premaxillary morphology, particularly increased depth and volume, may be associated with palatal MCI. These results support the concept that premaxillary morphology may represent an important anatomical factor influencing canine eruption patterns.

Ethics

Ethics Committee Approval: Approved by the Sri Ramachandra Institute of Higher Education and Research Ethics Committee for Student Projects (approval no: CSP/25/JAN/155/26, date: 27.03.2025).

Informed Consent: This retrospective observational study.

Footnotes

Author Contributions: Surgical and Medical Practices - J.T., B.S., V.K.; Concept - J.T., B.S., V.K.; Design - J.T., B.S., V.K.; Data Collection and/or Processing - J.T., B.S., V.K.; Analysis and/or Interpretation - J.T., B.S., V.K.; Literature Search - J.T., B.S., V.K.; Writing - J.T., B.S., V.K.

Conflict of Interest: No conflict of interest was declared by the authors.

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Original Article

Comparison of the Effects of Functional Treatment and Orthognathic Surgery on Hyoid Bone Position Following Mandibular Advancement

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Main Points

- Functional treatment and orthognathic surgery involving mandibular advancement can influence the position of the hyoid bone in individuals with skeletal Class II malocclusion.
- Functional treatment results in an antero-inferior displacement of the hyoid bone.
- Orthognathic surgery induces predominantly superior displacement of the hyoid bone with limited anteroposterior change.
- Hyoid position remained largely stable in untreated skeletal Class II individuals.

ABSTRACT

Objective: To compare the effects of functional orthopedic treatment and mandibular advancement induced by orthognathic surgery on hyoid bone position in individuals with skeletal Class II malocclusion, relative to an untreated control group.

Methods: Fifty-six individuals were divided into functional (n=20), surgical (n=16), and control groups (n=20). Lateral cephalometric images obtained at pretreatment (T0) and posttreatment (T1) were analyzed using WebCeph software. The linear (aC2-H, aC3-H, aC4-H, S-H, N-H, ANS-PNS-H) and angular (SNA, SNB, ANB, Go-H-S, H-S-N, H-PNS-ANS) describing hyoid bone position were measured. Data normality was assessed with the Shapiro-Wilk test, followed by one-way ANOVA or Kruskal-Wallis test, as appropriate. Intragroup changes were evaluated using paired tests, and post-hoc analyses were performed using Tukey honestly significant difference or Dunn-Bonferroni methods. Measurement reliability was confirmed (intraclass correlation coefficients >0.90).

Results: At T0, the orthognathic surgery group showed significantly higher aC2-H, aC3-H, aC4-H, S-H, N-H, and ANS-PNS-H measurements compared to the other groups ($p<0.05$), while angular variables did not differ significantly. At T1, intergroup differences in hyoid position were no longer significant ($p>0.05$). Intragroup analysis revealed significant increases in aC2-H, aC4-H, S-H, and N-H in the functional treatment group, whereas significant decreases in N-H, H-S-N, and H-PNS-ANS were observed in the orthognathic surgery group. Changes in the control group were minimal.

Conclusion: Functional treatment resulted in anterior-inferior displacement of the hyoid bone, whereas orthognathic surgery predominantly induced superior displacement without significant anteroposterior change. Both treatment modalities improved mandibular skeletal relationships, while hyoid position remained largely stable in untreated individuals.

Keywords: Hyoid bone, mandibular advancement, orthognathic surgery

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INTRODUCTION

The treatment of Class II malocclusions depends on multiple factors, including the severity of the maxillomandibular discrepancy, patient age, morphological characteristics of dental and skeletal structures, soft-tissue conditions, growth and developmental stage, and etiology of the malocclusion.[1] In growing patients, growth modification with functional appliances is generally considered the treatment of choice.[2,3] These appliances transmit functional forces to the jaws through the dentition, and with regular use, may improve the underlying skeletal discrepancy.[2-4] In patients with severe skeletal discrepancies who have completed growth and are not suitable candidates for camouflage treatment, combined orthodontic and orthognathic surgical treatment is indicated to reposition the dentofacial and skeletal structures.[5] Mandibular advancement is expected to induce positional changes in the jaws and associated skeletal landmarks during both functional treatment and orthognathic surgery. In this context, the position of the hyoid bone, which has a close anatomical and functional relationship with the mandible, may also be affected by these movements.

The hyoid bone, a freely movable structure located inferior to the mandible in the anterior midline of the neck, is an important component of the stomatognathic system.[6] Given its muscular attachments to adjacent structures, particularly the mandible, the position of the hyoid is influenced by functional activities such as mastication, swallowing, and respiration. Moreover, these muscular connections allow the hyoid bone to perform complex movements in coordination with mandibular motion. Several studies have demonstrated synchronous movement of the hyoid bone and mandible in the sagittal plane.[7-9] Furthermore, the hyoid musculature contributes to stabilization and dilation of the pharyngeal airway, and anterior displacement of the hyoid bone increases the resistance of the upper airway to collapse.[10,11] Therefore, hyoid position plays a critical role in conditions associated with upper airway narrowing, particularly obstructive sleep apnea (OSA).[12,13] Accordingly, skeletal Class II malocclusion characterized by mandibular retrusion and an inferiorly positioned hyoid bone has been identified as a risk factor for OSA.[14]

Correction of skeletal Class II malocclusion may reposition the mandible to a more favorable position, with anterior displacement of the hyoid bone and subsequent improvement in airway dimensions. To prevent potential respiratory problems, Li[15] recommended early orthodontic treatment in skeletal Class II patients with mandibular deficiency. Such treatment aims to advance the mandible, hyoid bone, tongue, and soft palate anteriorly, thereby increasing oropharyngeal dimensions and reducing the risk of airway obstruction.[16] In skeletally mature Class II individuals, orthognathic surgery is performed to reposition the mandible anteriorly. This advancement is generally accompanied by anterior displacement of the hyoid bone and an increase in airway dimensions. However, the extent and direction of the effects of this surgical advancement on hyoid bone position, compared with early Class II treatment applied during the growth period, remain insufficiently clarified in the literature. In the present study, lateral cephalometric radiographs (CEPH) were used to identify these positional changes. Despite certain limitations, CEPH are widely accepted and commonly used to evaluate orthodontic and orthognathic treatment outcomes.[9]

Only a limited number of studies have investigated hyoid positional changes following functional treatment or orthognathic surgery. However, no study to date has compared these two treatment modalities within the same study design while also including an untreated control group. Therefore, the aim of this study was to evaluate the effects of mandibular advancement, achieved by functional treatment and orthognathic surgery, on hyoid bone position. Changes observed in the treatment groups were also compared with natural growth patterns in untreated skeletal Class II individuals. The null hypothesis was that changes in hyoid bone position would not differ significantly among the functional treatment, orthognathic surgery, and control groups.

METHODS

Study Design and Patient Selection

This retrospective study used lateral CEPH of patients with skeletal Class II malocclusion who underwent functional orthopedic treatment or orthognathic surgery at the Department of Orthodontics, Faculty of Dentistry, İnönü University and whose records were available in the institutional archive. All CEPH were obtained using the same radiographic unit (Planmeca Proline XC, 00880 Helsinki, Finland) with standardized exposure parameters (72 kV, 6.0 mA, 18.7 s). Radiographs were taken with the ear rods positioned in the external auditory canals, the teeth in maximum intercuspation, the lips at rest, and the Frankfort horizontal plane parallel to the floor.

Ethical approval was obtained from the İnönü University Scientific Research Ethics Committee (approval no: 2025/8835, date: 02.12.2025). The cephalometric landmarks used in the study are illustrated in Figure 1.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: (1) skeletal Class II malocclusion [a point-nasion-b point (ANB) angle ≥ 4°]; (2) availability of high-quality lateral CEPH at the required time points; (3) completion of the respective treatment protocol for the functional and orthognathic groups; and (4) no history of orthodontic treatment in the control group. Exclusion criteria included the following: (1) craniofacial syndromes; (2) a history of maxillofacial trauma; (3) systemic conditions affecting growth and development; and (4) incomplete or poor-quality cephalometric records.

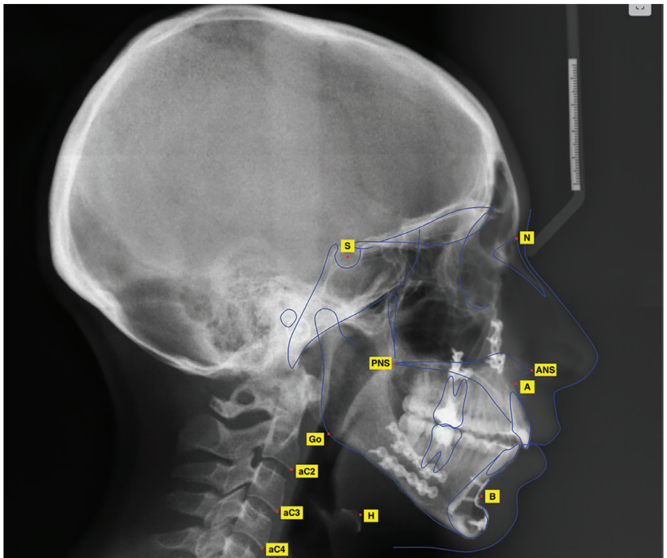

Figure 1. Cephalometric landmarks used in the study. S: Sella (central point of the pituitary fossa); N: Nasion (most anterior point of the frontonasal suture); A: Point A (deepest anterior point of the upper labial alveolar concavity.); B: Point B (deepest anterior point of the lower labial alveolar concavity); ANS: Anterior nasal spine (most anterior point of the pre-maxillary bone); PNS: Posterior nasal spine (posterior point of the hard palate); Go: Gonion (most posterior-inferior point at the angle of the mandible); H: Hyoidale (most anterosuperior point of the hyoid bone); aC2, aC3, aC4: Anteroinferior points of the second, third, and fourth cervical vertebrae, respectively.

Three study groups were established:

- **Group 1 (functional treatment group):** Individuals treated exclusively with removable functional orthopedic appliances during the growth period.
- **Group 2 (orthognathic surgery group):** Individuals with skeletal Class II malocclusion who underwent mandibular advancement surgery. The majority of patients (n=12, 75%) underwent bimaxillary surgery, including maxillary impaction, whereas the remaining patients (n=4, 25%) underwent mandibular advancement alone.
- **Group 3 (control group):** Untreated individuals with skeletal Class II malocclusion.

Inclusion criteria for the functional treatment group consisted of patients who had completed treatment with functional appliances, such as a Monoblock, during the growth period. Treatment protocols were based on standard clinical practice in our department. No rapid maxillary expansion was performed in conjunction with functional appliance therapy. The appliance was used for approximately 12 months, comprising an active phase of approximately 8 months of full-time wear, followed by a retention phase of approximately 4 months of night-time wear. Exact treatment durations could not be fully standardized across all patients due to the retrospective nature of the study; however, all patients followed a similar clinical protocol.

The orthognathic surgery group included adult patients with skeletal Class II malocclusion who had completed growth. All individuals in this group underwent bilateral sagittal split osteotomy for mandibular advancement. Rigid internal fixation was achieved using titanium plates and screws. An occlusal splint was used intraoperatively and maintained for two weeks postoperatively as part of the stabilization protocol. Due to the retrospective design of the study, detailed evaluation of phase-specific treatment durations was limited. Pre-surgical orthodontic treatment was performed to achieve appropriate dental decompensation, followed by the surgical phase and post-surgical orthodontic finishing. The overall treatment duration was approximately 3.37±0.79 years.

The control group consisted of individuals with skeletal Class II relationships (ANB ≥4°) who had not received orthodontic treatment. Most subjects were in the pre-peak growth phase who were under clinical follow-up while awaiting appropriate timing for functional treatment. Selection of this group was based on the availability of untreated individuals within the institutional archive who met the inclusion criteria, while also considering ethical constraints related to unnecessary radiation exposure and withholding treatment. Accordingly, a limited number of skeletally mature individuals awaiting surgical intervention were also included. However, the overall age distribution indicates that the control group consisted predominantly of individuals in the growth period, which may help differentiate between treatment-related changes and physiological growth-related adaptations.

A priori power analysis was performed to determine the required sample size. For a three-group study design, a power analysis conducted using G*Power software (version 3.1; Heinrich Heine University of Düsseldorf, Germany) indicated that a minimum of 54 participants would be sufficient (effect size f=0.25, α=0.05, power=0.90).[17] A total of 56 individuals were included in the present study. Descriptive statistics of the study sample are presented in Table 1.

Cephalometric Analysis and Measurements

Pre-treatment (T0) and post-treatment (T1) lateral CEPH of all participants were analyzed using version 2.0 (AssembleCircle Corp., Republic of Korea), an artificial intelligence-assisted, web-based, automated analysis platform.[18] Prior to analysis, all radiographs were calibrated within the software. Following image upload, the system automatically identified anatomical reference points (landmarks). To ensure measurement accuracy, all landmark positions were individually reviewed by an experienced operator (H.G.O.), and any inaccurately placed landmarks were manually corrected.

To assess measurement reliability, a randomly selected subset of 15 patients was reanalyzed. All landmarks were re-evaluated by the same operator after a two-week interval to determine intra-operator reliability and were independently reassessed by a second operator (F.O.) to evaluate inter-operator reliability.

Table 1. Descriptive statistics for the groups				
Group	**n**	**Female**	**Male**	**Mean age (years ± SD)**
Functional Group	20	10	10	12.71±0.96
Orthognathic Group	16	11	5	17.90±1.59
Control Group	20	10	10	11.95±1.72
Total	56	31	25	13.92 ± 2.93

SD, standard deviation, n = sample size.

Measurement variables were selected from angular and linear parameters commonly used in the literature to evaluate hyoid bone position and sagittal mandibular changes in skeletal Class II individuals (Table 2, Figures 1 and 2). Based on the defined cephalometric landmarks and reference planes, skeletal measurements reflecting the anteroposterior and vertical position of the hyoid bone, as well as the degree of mandibular advancement, were digitally recorded.

Statistical Analysis

All statistical analyses were performed using the R statistical software (version 4.5; R Foundation for Statistical Computing, Vienna, Austria) and RStudio 2025 (version 2025.05.1+513; Posit Software, Boston, MA, USA). Normality of the data distribution within each group was assessed using the Shapiro-Wilk test, with p>0.05 indicating normal distribution. Homogeneity of variances was evaluated using Levene's test, with p>0.05 indicating equality of variances for sella-nasion-a point (SNA) angle, sella-nasion-b point (SNB) angle, H-S-N, H-PNS-ANS, and ANS-PNS-H.

Variables meeting parametric assumptions (ANB, aC2-H, aC3-H, aC4-H, S-H, N-H, and Go-H-S), intergroup were analyzed using one-way analysis of variance (ANOVA). Variables that did not satisfy these assumptions were analyzed using the Kruskal-Wallis H test. Sex distribution among groups was compared using the chi-square test. When statistically significant differences were identified, post-hoc analyses were conducted using Tukey's honestly significant difference test following ANOVA and the Dunn-Bonferroni test following the Kruskal-Wallis test. Sex-related differences were assessed using the Mann-Whitney U test for within-group comparisons and analysis of covariance (ANCOVA), including the group × sex interaction, for comparisons of treatment-related changes. Statistical significance was set at p<0.05 for all analyses.

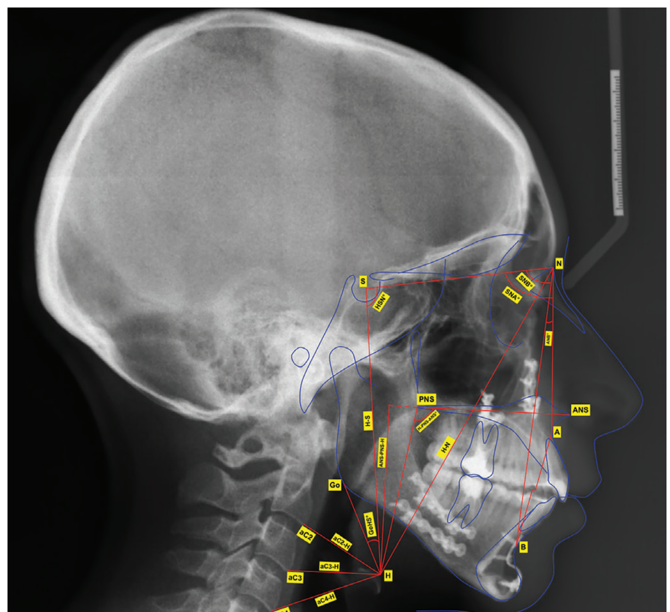

Figure 2. Cephalometric landmarks and measurements used in the study.

Table 2. Condylar morphometric parameters and definitions	
Measurement	**Description**
SNA°	Maxillary sagittal position relative to the cranial base (S; sella, N; nasion, A; point A).
SNB°	Mandibular sagittal position relative to the cranial base (B; point B).
ANB°	Sagittal skeletal discrepancy between maxilla and mandible.
Go-H-S°	Angle formed between gonion (Go), hyoid (H), and sella (S).
H-S-N°	Angle formed between the hyoid (H), sella (S), and nasion (N).
H-ANS-PNS°	Angle formed between the hyoid (H) and the palatal plane (ANS-PNS).
aC2-H (mm)	Distance from hyoid bone to the anteroinferior point of C2.
aC3-H (mm)	Distance from hyoid bone to the anteroinferior point of C3.
aC4-H (mm)	Distance from hyoid bone to the anteroinferior point of C4.
S-H (mm)	Distance from sella (S) to the hyoid bone (H).
N-H (mm)	Distance from nasion (N) to the hyoid bone (H).
ANS-PNS-H (mm)	Vertical distance between the hyoid bone and the palatal plane (ANS-PNS).

SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

RESULTS

A total of 56 individuals were included in the functional treatment, orthognathic surgery, and control groups (Table 1). Reliability analysis demonstrated excellent measurement consistency, with intrarater and interrater intraclass correlation coefficients exceeding 0.90 for all cephalometric variables. No statistically significant difference in sex distribution was observed among the three groups (chi-square test, χ^2=1.626, df=2, p=0.444).

Baseline (T0) measurements are presented in Figure 3 and Table 3. Significant intergroup differences were also observed in several hyoid bone positional measurements. Specifically, linear measurements were significantly higher in the orthognathic surgery group than in the other groups ($p<0.05$). Post-hoc analyses confirmed that the functional treatment group had significantly lower hyoid positional values than the orthognathic surgery group. In contrast, no statistically significant differences were observed for the SNA, SNB, ANB, Go-H-S, H-S-N, or H-PNS-ANS measurements among the three groups ($p>0.05$; Table 3). Post-treatment (T1) measurements are presented in Figure 4 and Table 4. No statistically significant differences were observed among the groups for any variable ($p>0.05$; Table 4). Changes between T0 and T1 are presented in Figure 5 and Table 5. Although significant intergroup differences were observed for some variables, the majority of the parameters did not show any significant differences after treatment.

The intragroup changes between the T0 and T1 periods are presented in Figure 6. Significant changes were observed in the functional treatment group for aC2-H, aC4-H, S-H, N-H, ANS-PNS-H, SNB, and ANB measurements. In the orthognathic surgery group, significant changes were found for the variables N-H, SNA, SNB, H-S-N, and H-PNS-ANS variables. In the control group, only S-H and ANB showed significant changes. Significant sex-related differences (ΔT1-T0) were observed in the functional treatment group for aC2-H (p=0.029), S-H (p=0.015), and ANS-PNS-H (p=0.029), whereas no significant differences were observed in the other groups ($p>0.05$; Supplementary Table 1). ANCOVA demonstrated no main effect of sex on the magnitude of change.

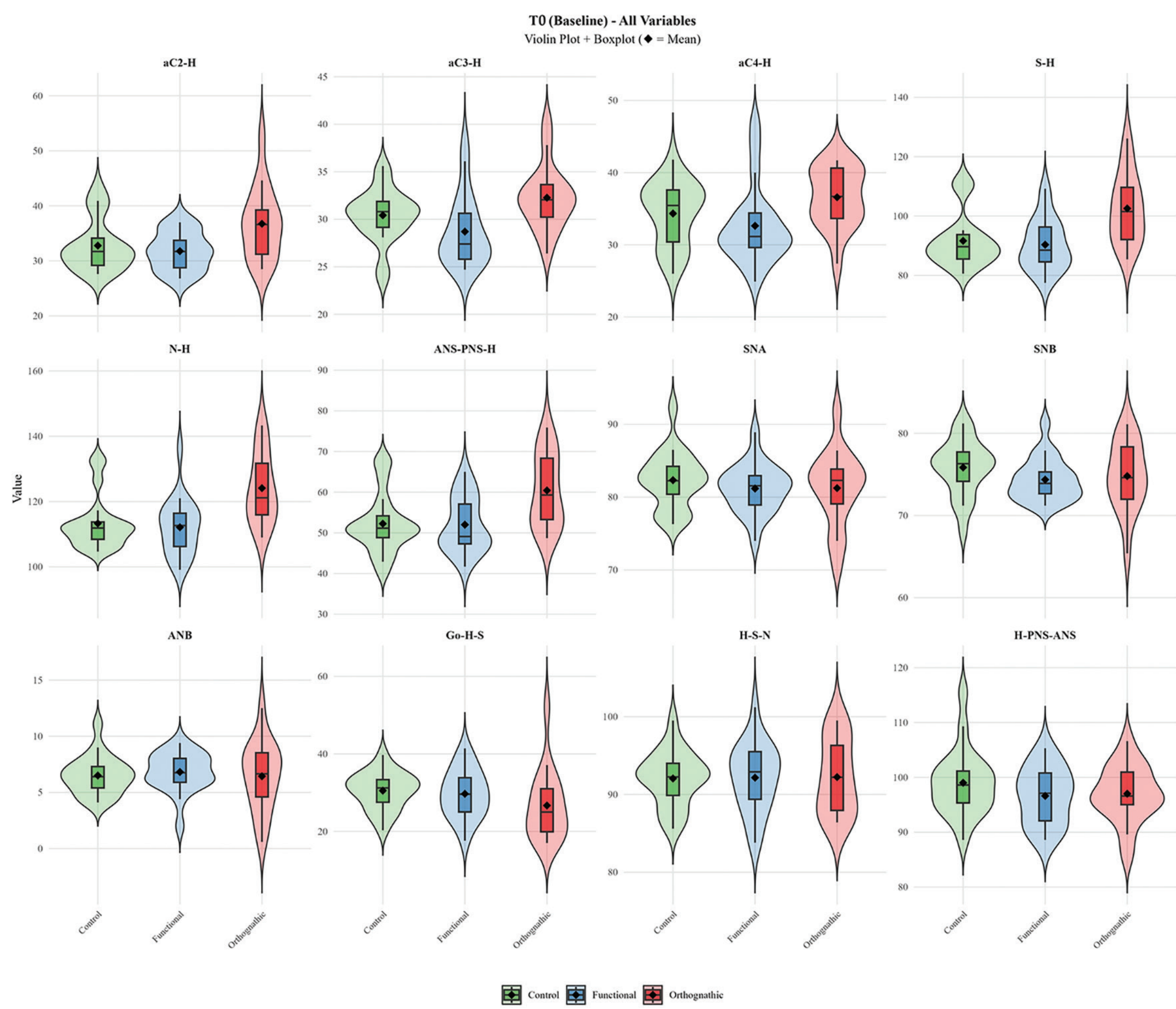

Figure 3. Violin and box plots illustrating the distribution of linear and angular measurements related to hyoid bone position in the control, functional treatment, and orthognathic surgery groups at baseline (T0).

Table 3. Descriptive statistics of pretreatment (T0) measurements across the three study groups

Variable	Control group	Functional group	Orthognathic group	p-value
SNA (°)	82.33±3.90	81.18±3.29	81.24±5.26	0.648
SNB (°)	75.84±3.35	74.36±2.59	74.79 ±4.19	0.246
ANB (°)	6.50±1.73	6.82±1.73	6.44±3.06	0.713
Go-H-S (°)	30.51±4.82	29.69±6.23	26.68±9.14	0.100
H-S-N (°)	92.05±3.49	92.16±4.35	92.23±4.84	0.969
H-PNS-ANS (°)	99.02±6.13	96.61±5.15	97.02±5.19	0.548
aC2-H (mm)	32.77±4.70	31.77±3.42	36.74±6.52	0.040*
aC3-H (mm)	30.41±2.83	28.70±3.69	32.27±3.42	0.006**
aC4-H (mm)	34.34±4.36	32.63±5.45	36.59±4.09	0.023*
S-H (mm)	91.64±9.06	90.33±8.54	102.55±11.71	0.002**
N-H (mm)	113.30±8.17	112.11±8.68	124.11±10.77	0.001**
ANS-PNS-H (mm)	52.26±7.35	52.01±6.63	60.42±8.97	0.006**

*p<0.05; **p<0.01. Values are presented as mean ± standard deviation.
SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

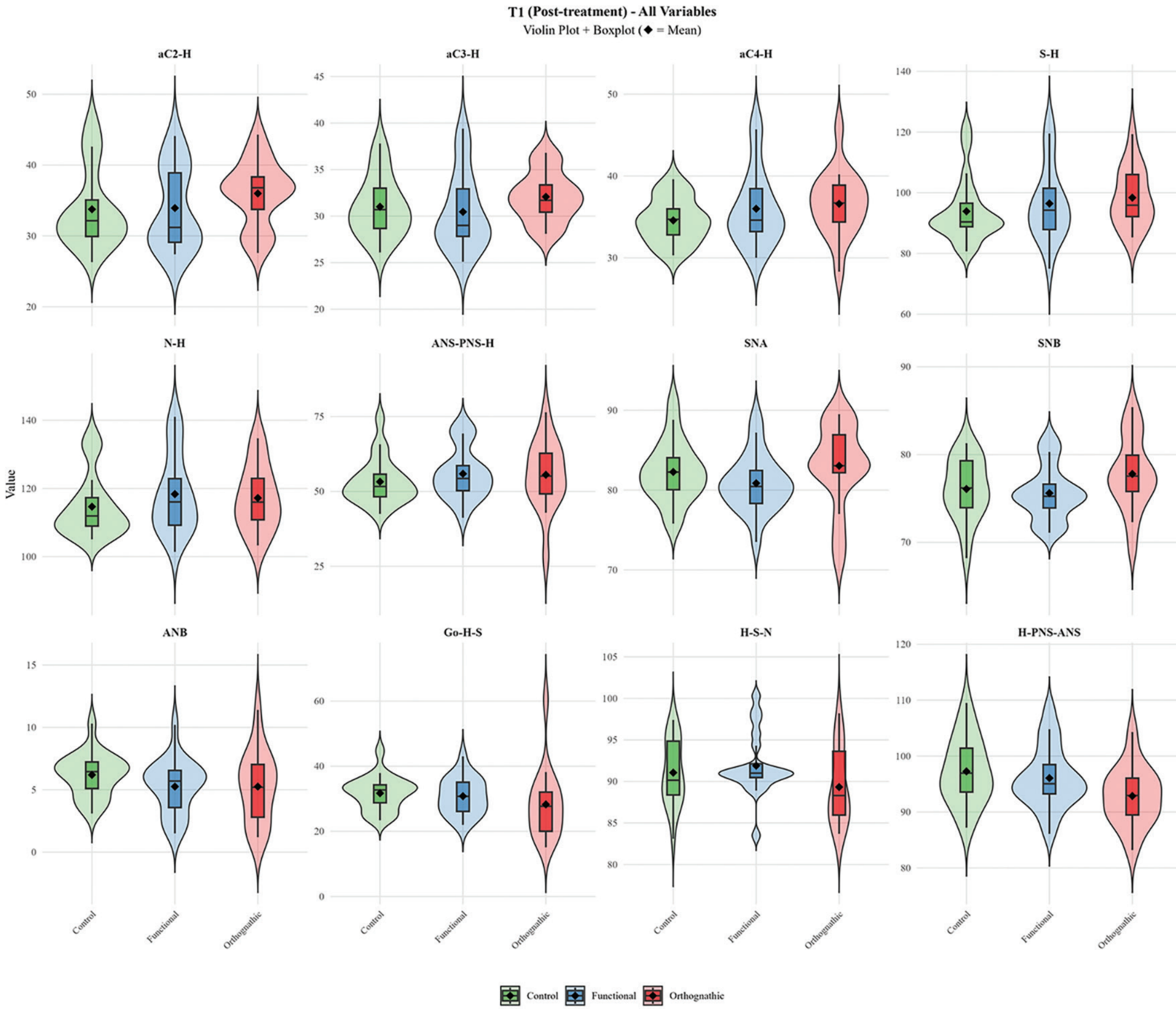

Figure 4. Violin and box plots illustrating the distribution of linear and angular measurements related to hyoid bone position in the control, functional treatment, and orthognathic surgery groups post-treatment (T1).

Table 4. Descriptive statistics of postreatment (T1) measurements across the three study groups

Variable	Control group	Functional group	Orthognathic group	p-value
SNA (°)	82.27±3.86	80.86±3.59	83.04±5.26	0.099
SNB (°)	76.08±3.48	75.61±3.08	77.80±4.24	0.179
ANB (°)	6.20±1.72	5.25±2.11	5.26±2.87	0.236
Go-H-S (°)	31.72±5.20	30.80±5.57	28.28±10.92	0.155
H-S-N (°)	91.06±3.89	91.89±3.78	89.33±4.57	0.080
H-PNS-ANS (°)	97.27±5.92	96.06±5.55	92.86±5.26	0.073
aC2-H (mm)	33.76±5.63	33.94±5.70	35.99±4.67	0.416
aC3-H (mm)	31.00±3.20	30.46±4.14	32.08±2.67	0.196
aC4-H (mm)	34.56±2.71	35.99±4.61	36.60±4.02	0.261
S-H (mm)	93.88±10.49	96.45±12.46	98.39±9.62	0.310
N-H (mm)	114.66±9.20	118.34±11.49	117.21±9.57	0.488
ANS-PNS-H (mm)	53.23±7.73	55.89±8.66	55.55±11.38	0.442

Values are presented as mean ± standard deviation.
SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

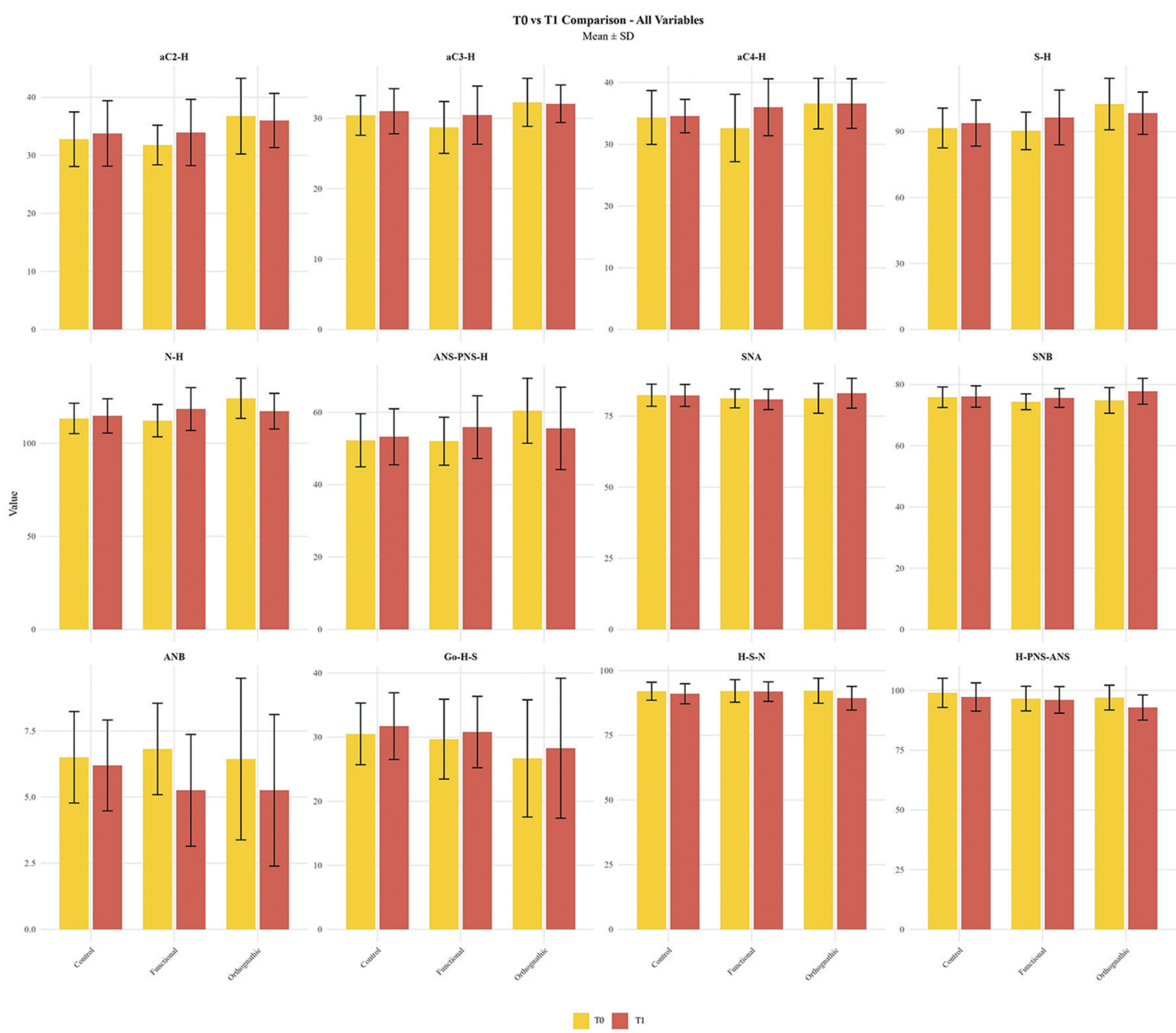

Figure 5. Bar charts illustrating mean ± standard deviation values of linear and angular measurements related to hyoid bone position at baseline (T0) and post-treatment (T1) in the control, functional treatment, and orthognathic surgery groups. Yellow bars represent T0 values and red bars represent T1 values. Error bars indicate standard deviations.

Table 5. Intergroup comparison of pre- (T0) and posttreatment (T1) and it's treatment related changes (ΔT1-T0)

Measurement	Control (n=20)				Functional (n=20)				Orthognathic (n=16)				Group comparison
	T0	T1	Δ T1-T0	p-value[a]	T0	T1	Δ T1-T0	p-value[a]	T0	T1	Δ T1-T0	p-value[a]	p-value[b]
SNA	82.33 (3.90)	82.27 (3.86)	-0.06 (1.79)	0.751	81.18 (3.29)	80.86 (3.59)	-0.32 (1.61)	0.385	81.24 (5.26)	83.04 (5.26)	+1.80 (1.75)	<0.001**	0.099
SNB	75.84 (3.35)	76.08 (3.48)	+0.24 (1.84)	0.567	74.36 (2.59)	75.61 (3.08)	+1.25 (1.82)	0.006**	74.79 (4.19)	77.80 (4.24)	+3.01 (2.11)	<0.001**	0.179
ANB	6.50 (1.73)	6.20 (1.72)	-0.31 (0.60)	0.031*	6.82 (1.73)	5.25 (2.11)	-1.57 (1.28)	<0.001**	6.44 (3.06)	5.26 (2.87)	-1.18 (2.31)	0.059	0.236
Go-H-S	30.51 (4.82)	31.72 (5.20)	+1.21 (5.85)	0.367	29.69 (6.23)	30.80 (5.57)	+1.11 (5.58)	0.385	26.68 (9.14)	28.28 (10.92)	+1.59 (5.89)	0.296	0.155
H-S-N	92.05 (3.49)	91.06 (3.89)	-0.99 (3.37)	0.204	92.16 (4.35)	91.89 (3.78)	-0.27 (3.61)	0.746	92.23 (4.84)	89.33 (4.57)	-2.91 (2.80)	<0.001**	0.080
H-PNS-ANS	99.02 (6.13)	97.27 (5.92)	-1.75 (5.30)	0.156	96.61 (5.15)	96.06 (5.55)	-0.55 (4.73)	0.606	97.02 (5.19)	92.86 (5.26)	-4.16 (5.12)	0.005**	0.073
aC2-H	32.77 (4.70)	33.76 (5.63)	+0.99 (2.89)	0.142	31.77 (3.42)	33.94 (5.70)	+2.16 (4.14)	0.030*	36.74 (6.52)	35.99 (4.67)	-0.74 (4.50)	0.623	0.416
aC3-H	30.41 (2.83)	31.00 (3.20)	+0.59 (3.21)	0.421	28.70 (3.69)	30.46 (4.14)	+1.76 (4.42)	0.092	32.27 (3.42)	32.08 (2.67)	-0.19 (2.95)	0.796	0.196
aC4-H	34.34 (4.36)	34.56 (2.71)	+0.22 (5.26)	0.850	32.63 (5.45)	35.99 (4.61)	+3.37 (5.98)	0.021*	36.59 (4.09)	36.60 (4.02)	+0.01 (4.00)	0.990	0.261
S-H	91.64 (9.06)	93.88 (10.49)	+2.24 (4.66)	0.044*	90.33 (8.54)	96.45 (12.46)	+6.12 (9.11)	0.007**	102.55 (11.71)	98.39 (9.62)	-4.16 (9.97)	0.256	0.310
N-H	113.30 (8.17)	114.66 (9.20)	+1.36 (4.30)	0.174	112.11 (8.68)	118.34 (11.49)	+6.23 (11.24)	0.023*	124.11 (10.77)	117.21 (9.57)	-6.90 (11.21)	0.011*	0.488
ANS-PNS-H	52.26 (7.35)	53.23 (7.73)	+0.97 (3.72)	0.256	52.01 (6.63)	55.89 (8.66)	+3.71 (6.98)	0.032*	60.42 (8.97)	55.55 (11.38)	-4.88 (9.24)	0.059	0.442

[a]dependent samples t-test, [b]independent samples t-test/Kruskal-Wallis test, *p<0.05, **p<0.01.
Values are presented as mean ± SD.
SD: standard deviation; SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

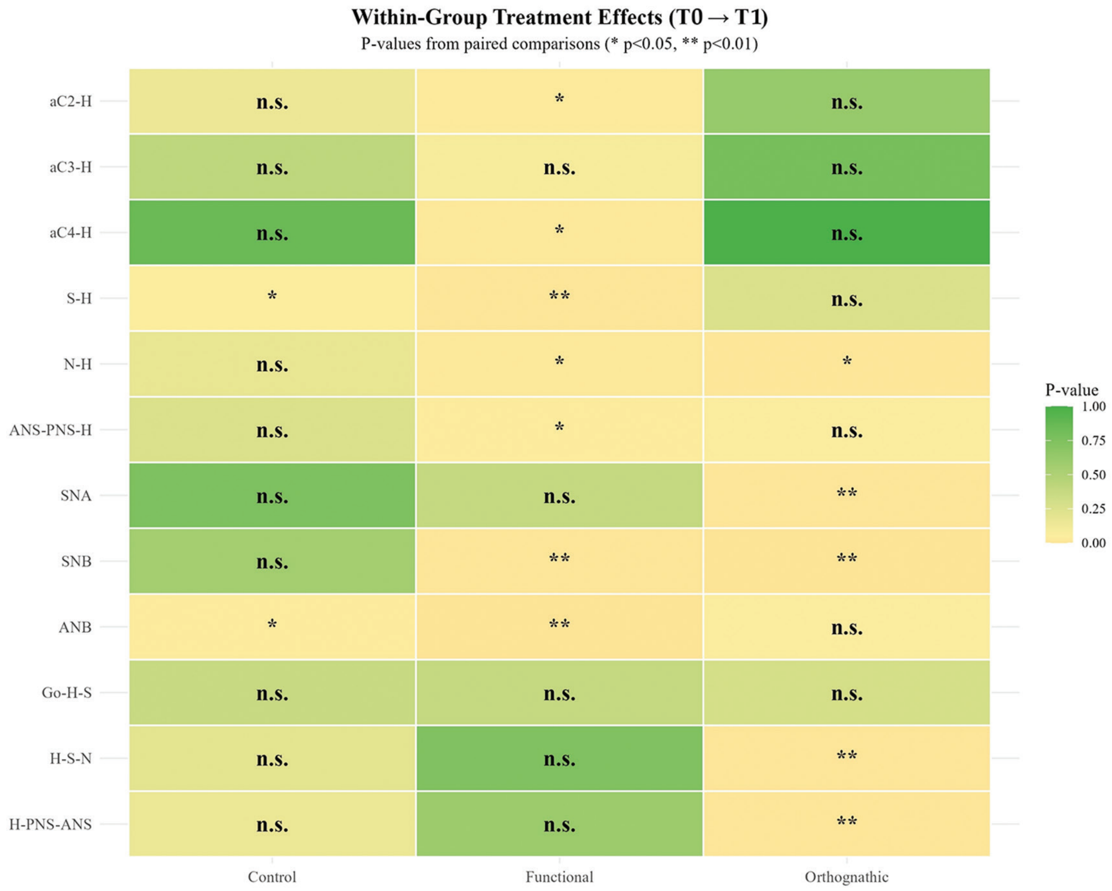

Figure 6. Heatmap illustrating within-group treatment effects (T0-T1) for all linear and angular variables in the control, functional treatment, and orthognathic surgery groups. Statistical significance is denoted as follows: *p<0.05; **p<0.01; n.s., not significant.

DISCUSSION

The aim of the present study was to evaluate the effects of mandibular advancement achieved through functional treatment and orthognathic surgery on hyoid bone position and to compare the resulting changes with those observed in an untreated control group. Accordingly, the null hypothesis of the study was that there would be no statistically significant differences in positional changes of the hyoid bone among the three groups. Because significant differences were identified in several measurements, the null hypothesis was rejected.

In the present study, the orthognathic surgery group exhibited significantly greater pre-treatment aC2-H, aC3-H, aC4-H, S-H, N-H, and ANS-PNS-H values than the functional treatment and control groups. These measurements represent distances between the hyoid bone and superior or anterior craniofacial reference points. In contrast, no significant differences were observed among the groups for the SNA, SNB, ANB, Go-H-S, H-S-N, or H-PNS-ANS measurements. However, all intergroup differences disappeared after treatment, and the positional parameters of the hyoid bone were comparable across the groups. The greater pre-treatment hyoid distances observed in the orthognathic surgery group suggest a more posterior-inferior hyoid position in these patients. This can be attributed to the generally older age of patients in this group and the progressive development of compensatory head-neck posture. Indeed, there is evidence that the hyoid bone tends to shift inferiorly and slightly posteriorly with age, and this positional adaptation develops in accordance with mandibular growth and respiratory requirements.[19]

The untreated control group exhibited only minor changes over time, including a slight increase in the S-H distance and a small decrease in ANB. These findings are consistent with natural craniofacial changes associated with growth and development. In a longitudinal study conducted by Ochoa and Nanda[20] on individuals aged 6 to 20 years, the ANB angle decreased until approximately 14 years of age. The limited magnitude of these changes and the absence of significant differences in the remaining parameters indicate that the positional stability of the hyoid bone was largely preserved in the control group. Matsuda et al.[21] reported that the hyoid bone shifts posteriorly and inferiorly with advancing age in individuals aged 22-84 years, and is pronounced in males over 60 years of age. Furthermore, cone-beam computed tomography-based studies conducted in subjects aged 6-18 years have demonstrated that significant changes in hyoid position may occur after puberty, in parallel with craniofacial growth.[22] In the present study, the limited changes observed in the control group may be attributed to the relatively short follow-up period. Furthermore, the retrospective design of the study restricted the duration of follow-up and may have limited the ability to detect more pronounced growth-related changes.

Functional treatment led to significant increases in aC2-H, aC4-H, S-H, N-H, and ANS-PNS-H, which represent the distances from the hyoid bone to cervical reference points. In addition, the change in the SNA angle was not significant, while the SNB angle showed a significant increase, indicating anterior repositioning of the mandible following functional treatment. The significant decrease in the ANB angle also suggested a marked improvement in the skeletal Class II relationship. Zhou et al.,[23] Ulusoy et al.,[9] and Hourfar et al.[24] have reported that the hyoid bone assumes a more inferior and anterior position after functional treatment, which is consisting with our findings as well. Anterior advancement of the mandible through functional therapy leads to anterior displacement of the hyoid bone via muscular attachments.[9,23-27] Furthermore, the eruption of the second molars and growth-related increases in lower facial height contribute to inferior positioning of the hyoid bone by promoting clockwise rotation of the mandible.[11] Sambale et al.[11] reported significant anterior movement of the hyoid bone following functional appliance therapy, as indicated by increased distances from the aC2, aC3, and aC4 reference points. However, unlike the present findings, they also reported a superior displacement of the hyoid bone. This discrepancy may be attributed to methodological differences in the cephalometric reference points. In the previous study, hyoid position was assessed primarily by the perpendicular distance from the hyoid bone to the mandibular plane; in our study, hyoid position was evaluated using the S-H and N-H planes. Nevertheless, Sambale et al.[11] also observed a trend toward increasing S-H and N-H distances in their study. Overall, the changes in SNA, SNB, and ANB are consistent with craniofacial responses reported for the activator and similar functional appliances.[28,29] These findings support the ability of functional treatment to enhance sagittal mandibular development and improve skeletal Class II relationships. Moreover, this treatment-related skeletal response appears biomechanically consistent with the anterior positional changes observed in the hyoid bone.

The N-H measurement, representing the distance between the hyoid bone and anterosuperior reference structures, decreased significantly after orthognathic surgery. Likewise, significant reductions were observed in the H-S-N and H-PNS-ANS angular measurements. In contrast, both SNA and SNB angles increased significantly after surgical intervention, confirming skeletal advancement of the jaws. Altogether, these findings indicate that orthognathic surgery causes hyoid bone displacement predominantly in the superior direction. However, the decrease in N-H measurement suggested limited anteroposterior involvement and a slight posterior displacement rather than a pronounced anterior shift. Therefore, the overall pattern of hyoid movement following surgery can be interpreted as a predominantly superior repositioning, accompanied by rotational adaptations. Consistent with this interpretation, no significant changes were observed in the aC2-H, aC3-H, and aC4-H measurements, which further support limited anterior displacement of the hyoid bone. Karslı and Altuğ[30] investigated changes in hyoid bone position following mandibular advancement surgery in patients with skeletal Class II malocclusion, and found that the hyoid bone exhibited superior displacement after bimaxillary surgery involving maxillary impaction combined with mandibular advancement. The findings of the present study regarding superior hyoid movement are consistent with their results. This may be explained by the fact that most patients in the orthognathic surgery group underwent bimaxillary surgery, with maxillary impaction representing a common surgical component that likely promoted counterclockwise mandibular rotation. Therefore, the superior hyoid displacement observed in the present study may be associated with the upward repositioning of the maxilla. Consistent with this explanation, reductions in the H-S-N and H-PNS-ANS angles suggest counterclockwise adaptation of the hyoid bone relative to mandibular repositioning.

We also compared the time- and treatment-related changes among the three groups to determine whether these treatment approaches produced distinguishable effect sizes in hyoid bone position. No significant intergroup differences were observed in the effect sizes of the linear and angular variables representing hyoid bone position. Thus although both treatment modalities produced significant changes in hyoid position, neither showed superiority in terms of overall magnitude of change. From a clinical perspective, the hyoid bone was predominantly displaced anteriorly after functional treatment, whereas superior displacement was more pronounced in the orthognathic surgery group. Therefore, although the direction of hyoid movement differed between treatment modalities, the overall magnitude of positional change appeared comparable. Anterior of the hyoid displacement is generally associated with forward movement of the tongue base and a potential increase in upper airway dimensions, whereas superior repositioning may reflect adaptive changes related to mandibular rotation and maxillary impaction. However, since airway dimensions and functional respiratory parameters were not directly assessed in the present study, further investigations are required to determine which pattern of hyoid movement may be clinically more advantageous. Changes observed in the control group were limited and were interpreted as physiological adaptations related to growth and development. Nevertheless, the magnitude of change did not differ significantly among the three groups. Since no study had simultaneously compared the outcomes of functional treatment and orthognathic surgery with an untreated control group, direct comparison with earlier studies was not possible.

However, our findings highlight the potential clinical relevance of functional orthopedic treatment, as it appears capable of producing hyoid adaptations comparable in magnitude to those observed after orthognathic surgery. Since functional treatment is applied during the growth period and avoids the morbidity associated with surgical intervention, its ability to induce measurable hyoid positional changes may represent a significant therapeutic advantage.

Study Limitations

This study has several limitations. First, the retrospective design limit complete control over patient selection and treatment heterogeneity. The number of patients in the orthognathic surgery group was relatively small, resulting in slight imbalance among the groups. Additionally, age and growth status were not fully matched, particularly between the growing functional and control groups and the skeletally mature surgical group. All evaluations were performed using lateral CEPH. Although orthognathic surgical procedures predominantly involved bimaxillary surgery, the extent of maxillary impaction and mandibular advancement varied among individuals, potentially influencing hyoid position and reducing treatment homogeneity. Furthermore, vertical facial pattern, a factor known to influence hyoid bone position, was not specifically controlled. Future studies should adopt prospective designs, utilize three-dimensional imaging modalities, investigate more homogeneous surgical samples, and include broader age ranges to better clarify treatment- and age-related effects on hyoid bone position.

CONCLUSION

Functional treatment led to significant antero-inferior displacement of the hyoid bone, whereas superior displacement was more pronounced following orthognathic surgery. Both treatment modalities resulted in significant skeletal changes, as reflected by improvements in SNB and ANB measurements. Only limited changes in hyoid position were observed in the untreated control group. Although the direction of hyoid displacement differed between functional treatment and orthognathic surgery, the overall magnitude of treatment-related change was comparable between the two approaches. In conclusion, neuromuscular and postural adaptation mechanisms activated by mandibular advancement may guide the hyoid bone toward a common equilibrium position, regardless of the treatment modality.

Ethics

Ethics Committee Approval: Ethical approval for the study was obtained from the İnönü University Scientific Research Ethics Committee (approval no: 2025/8835, date: 02.12.2025).

Informed Consent: Informed consent was waived due to the retrospective nature of the study.

Footnotes

Author Contributions: Surgical and Medical Practices – F.O., H.G.O.; Concept - F.O.; Design - F.O., H.G.O., T.K.; Data Collection and/or Processing - F.O., H.G.O.; Analysis and/or Interpretation - F.O., H.G.O., T.K.; Literature Search - F.O., H.G.O., T.K.; Writing - F.O., H.G.O., T.K.

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Original Article

Effect on Bracket Bonding of Polishing with Fluoride-Containing Prophy Paste Before Enamel Pretreatment with Orthophosphoric Acid: A Randomized Clinical Trial

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Main Points

- Among the 951 brackets assessed in this trial, the bond failure rate was 2.7%.
- Polishing with fluoride prophy paste resulted in fewer bracket bond failures than polishing with non-fluoride prophy paste, and the failure rates were much lower than those previously reported.
- Survival analysis showed that patient age and the presence of fluoride in the prophy paste affected bracket bonding.

ABSTRACT

Objective: This randomized clinical trial assessed the effects of polishing enamel with fluoride prophy paste before enamel pretreatment with orthophosphoric acid on bracket bond outcomes.

Methods: The study included 49 patients with a mean age of 24.6 years. Participants were randomly allocated to two groups in an approximate 1:1 ratio: 25 participants in the fluoride group (Group 1) and 24 in the non-fluoride group (Group 2). All patients' tooth surfaces were polished with prophy paste, etched, and fitted with brackets. Patients were followed up for 6 months. Outcome measures included bracket bond survival and the number of bond failures, along with questionnaire items collected from all subjects, such as history of fluoride varnish and mouthwash use, age, and sex. Survival time analysis was used to characterize bond failure outcomes.

Results: A total of 951 brackets were tested; the overall bond failure rate was 2.7%. Group 2 (non-fluoride polishing) had a bond failure rate of 4.0%, while Group 1 (fluoride polishing) had a significantly lower failure rate of 1.5%. These failure rates were much lower than those reported previously. Survival analysis, accounting for patient-level variability through random effects, revealed that age and fluoride prophy paste were significant risk factors. The hazard ratio for bond failure associated with the use of fluoride-containing prophy paste was 0.26.

Conclusion: Polishing with fluoride-containing prophy paste did not affect the bracket-bond failure rate when it was followed by phosphoric acid etching.

Keywords: Dental etching, dental enamel, Kaplan-Meier estimate

INTRODUCTION

In bracket bonding procedures, tooth polishing is typically performed before enamel pretreatment with orthophosphoric acid to remove organic pellicles.[1] Fluoride-free prophy paste is commonly used during this polishing because it is thought that fluoride-containing toothpaste might inhibit bonding by forming fluoroapatite, which

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resists the demineralization of enamel.[2] However, fluorapatite formation plays a crucial role in preventing white spot lesions around brackets.[3] Thus, it is important to explore the effects of fluoride varnish, toothpaste and mouthwash applications on bracket bonding.[4,5] In self-etching primer (SEP) procedures, the bracket bonding failure rate has been reported to be significantly higher when fluoride prophy paste is used for polishing, as compared to when fluoride-free paste is used.[6] In addition, some studies have reported that the bond strength between brackets and enamel is significantly lower following pretreatment with fluoride.[7,8] However, conflicting reports have suggested that adhesive strength either remains unaffected[9] or recovers over time.[10] Also, enamel etching with phosphoric acid appears to improve bracket bond strength; one study found that SEP treatment following enamel pretreatment with orthophosphoric acid yielded greater bond strength than did polishing with prophy paste alone.[11] A study using acidulated phosphate fluoride (APF) demonstrated that improvements in tooth surface properties due to fluorapatite formation require a considerable amount of time, which is why manufacturers recommend avoiding eating or drinking for at least 30 minutes following application.[10]

Thus, the changes in enamel surfaces briefly polished with fluoride-containing prophy paste and the effect thereof on bracket bonding remain uncertain. We hypothesized that fluoride-containing prophy paste would influence bracket bond failure rates, even with short-term use. This randomized clinical trial evaluated bracket bonding outcomes on enamel surfaces polished with either fluoride-containing or fluoride-free prophy paste, thereby elucidating the influence of fluoride-containing prophy paste on bracket bonding.

METHODS

Trial Design and Changes After Trial Commencement

This study was a prospective, single-center, randomized controlled clinical trial with a two-arm, parallel-group design and a 1:1 allocation ratio. The study protocol was registered with the University Hospital Medical Information Network Clinical Trials Registry (UMIN000056470).

Participants, Eligibility Criteria, and Setting

Recruitment for the bracket bonding study commenced in December 2022. Participants were recruited from among patients requiring orthodontic treatment with fixed appliances (standard 0.022-inch slot edgewise appliances) based on the following eligibility criteria:

Inclusion Criteria

1. Patients requiring orthodontic treatment with fixed appliances who had not previously undergone orthodontic treatment.
2. Patients with complete permanent dentition (excluding the third molars).
3. Teeth with intact enamel on the labial and buccal tooth surfaces intended for bracket bonding, and without dental caries, significant wear, enamel deficiencies (e.g., hypoplasia), or restorations or fractures.
4. Patients who agreed to comply with the trial protocol.

Exclusion Criteria

1. Patients with bonded brackets that interfered with occlusion.
2. Patients with craniofacial abnormalities (e.g., cleft lip and palate).
3. Patients who did not consent to participate in the study.

The study was conducted at a dental hospital affiliated with Nihon University School of Dentistry. A total of 49 patients (mean age, 24.6 years) with malocclusion who were scheduled for orthodontic treatment were enrolled. The bonding procedures were performed by 15 orthodontic residents, and bond-failure assessment was conducted by orthodontic specialists.

This study was approved by the Nihon University School of Dentistry Ethics Committee (approval number: EP22D014, date: 17.11.2024). The principal investigator (KH) initially screened the patients for eligibility. Participants who met the inclusion criteria were provided with detailed information about the study, including the patient information sheet and consent form. The consent form outlined the study's purpose, procedures, and potential risks and benefits in a question-and-answer format. Written informed consent was obtained from all participants or, in the case of minors, by their parents or guardians after the minors provided assent.

Sample Size Calculation

The sample size was calculated based on the ability to detect a 6.46% difference in the risk of bond failure (primary outcome) between the two trial arms (2.6% vs. 9.06%; α=0.05; power: 80%). Grover et al.[2] reported failure rates of 2.6% for bracket bonding with pumice and 9.06% for bracket bonding with fluoride varnish. These values were used as a reference for sample size calculation, indicating a requirement of 442 brackets in each arm, which was rounded up to 951 to account for loss to follow-up.

Interventions

Participants were randomly allocated to one of two groups. Group 1 (intervention group) (n=25) comprised 25 patients whose teeth were polished with a 1450-ppm fluoride-containing prophy paste before bracket bonding. Group 2 (control group) (n=24) comprised 24 patients whose teeth were polished with a fluoride-free prophy paste before bracket bonding. Before the start of the study, all orthodontic residents were instructed in the bonding protocol before study commencement. Prior to bonding, the teeth were polished using either a 1450-ppm fluoride-containing prophy paste (Check-Up Strea, Lion, Tokyo, Japan) or a fluoride-free prophy paste (Merssage AP Pro, Shofu, Shiga, Japan) (Figure 1), applied with a rubber cup or brush attached to a low-speed handpiece. The enamel surface was subsequently etched with 35% phosphoric acid (FinEtch, Spident, Incheon, Korea) for 30 seconds, rinsed with water to ensure complete removal of the etching agent, and dried. A light-cured adhesive primer (Transbond XT Light Cure Adhesive Primer, 3M Unitek, Monrovia, CA, USA) was then applied to the etched surface.

The following bracket systems were used: Invu (TP Orthodontics, IN, USA), Shine M (Mitsuba Ortho Supply, Tokyo, Japan), and Standard Edgewise Bracket (Tomy International, Tokyo, Japan). Brackets were bonded using Transbond XT Paste (3M Unitek) according to the manufacturer's instructions. Patients received dietary and oral hygiene instructions following bracket attachment. A total of 951 brackets were bonded during the study: 482 in Group 1 and 469 in Group 2.

Questionnaire

Information on prior fluoride varnish application and fluoride mouthwash use was collected from all participants via a questionnaire administered by the same researcher. The questionnaire included the following items:

1. How old are you?

2. Mark your sex:

a) Male

b) Female

3. Did you ever receive fluoride varnish at the dental office during childhood?

a) Yes

b) No

4. Did you ever use fluoride mouthwash at home during childhood?

a) Yes

b) No

Outcomes and Post-Commencement Trial Changes

Patients were examined at 3-4 week intervals to evaluate the presence or absence of bond failure. In addition, if a participant attended the clinic because of bracket detachment, between scheduled appointments, the event was recorded immediately as a bond failure. Following bond failure, the affected tooth was polished using conventional fluoride-free prophy paste, and the bracket was rebonded using a resin composite after phosphoric acid etching and primer application.

Interim Analyses and Stopping Guidelines

Not applicable.

Randomization and Allocation Concealment

Participants were randomly assigned to one of two groups using a computer-generated random-number generator (https://www.randomizer.org/). Allocation was performed by an investigator (KH) who was not involved in bracket bonding or outcome assessment. Before allocation, the operators informed the allocator of the number of teeth requiring bracket bonding and received the assigned prophy paste. The operators remained unaware of the type of prophy paste provided. Outcome assessment was performed by a separate investigator (YN), who was independent of both allocation and treatment procedures.

Blinding

The fluoride-containing and fluoride-free prophy pastes were visually indistinguishable and were transferred into identical, unlabeled containers before use (Figure 1). These containers were distributed to the operators to maintain blinding throughout the bonding procedures. The outcome assessor was also blinded to group allocation and analyzed the data using records identified only by randomly assigned participant numbers.

Statistical Analysis

Statistical analysis was conducted using software based on R and R Commander (EZR on R Commander, version 1.61; Jichi Medical

Figure 1. Prophy polishing pastes used in the study: paste containing fluoride (left) and paste without fluoride (right).

University, Saitama, Japan). Bracket survival during the 6-month follow-up period was estimated using the Kaplan-Meier method, with survival curves compared statistically via the log-rank test. Questionnaire-based experience with fluoride products, sex, age, and fluoride prophy paste were included as fixed effects, while patient-specific variation was modeled as a random effect (intraoral units). Statistical significance was set at $p<0.05$.

RESULTS

Participant Recruitment

A total of 80 patients were assessed for eligibility. Of these, 49 met the inclusion criteria, provided informed consent, and were allocated to the study. Group 1 received polishing with fluoride prophy paste before bracket bonding, and Group 2 received polishing with non-fluoride prophy paste before bracket bonding. Participant recruitment began in December 2022 and concluded in November 2023. Follow-up was completed in June 2024. All 49 enrolled patients completed the trial were included in the analysis. Figure 2 presents the CONSORT flow diagram for participants.

Baseline Participant Data

The mean age of participants was 24.6 years; 15 were aged 20 years or younger 65.3% were female and 34.7% were male (Table 1).

Experience With Fluoride Varnish And Fluoride Mouthwash

Table 1 lists participants' experience with fluoride varnish and fluoride mouthwash. The majority of participants reported no prior experience with either fluoride treatment. A higher proportion of participants had experience with fluoride varnish alone than with fluoride mouthwash; 6.1% had experience with both treatments.

Bond Failure Probabilities

A total of 951 brackets were evaluated during the study period. The overall bracket failure rate was 2.7%. The failure rates in Groups 1 and 2 were 1.5% and 4.0%, respectively (Table 2). Bond failures occurred more frequently in the mandibular arch. In the maxillary arch, posterior teeth exhibited a higher probability of bond failure than anterior teeth (Table 3).

Bond Failure By Group

Table 4 lists the bond failure probabilities by group, and Figure 3 presents the survival curves. The survival rates for Groups 1 and 2 were 0.985 [95% confidence interval (CI): 0.970-0.993] and 0.959 (95% CI: 0.937-0.974), respectively; both rates were very high. The probability of bond failure was significantly higher in Group 2 than in Group 1; the survival curve for Group 2 showed a slight decline during the early period.

Hazard Ratios Estimated Via Survival Analysis

The results of the survival analysis are shown in Table 5. When accounting for patient-level variability through random effects, age and type of prophy paste were identified as significant predictors of bond failure. The hazard ratios for age and fluoride prophy paste were 0.9208 and 0.2579, respectively.

The hazard ratio for bond failure with fluoride paste was 0.26 relative to that for non-fluoride prophy paste.

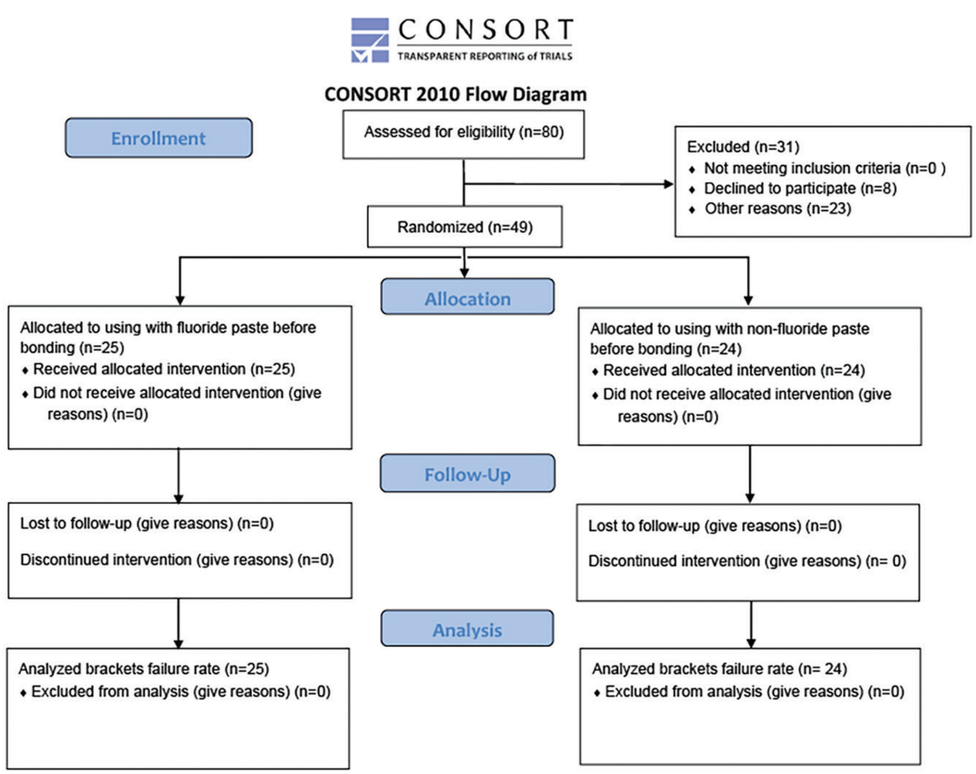

Figure 2. CONSORT flowchart diagram illustrating the recruitment, allocation, and follow-up of participants in this clinical trial.

Table 1. Patients' age, sex and experience in fluoride

	Number	Proportion (%)
Age (average age: 24.6 years) ≤20 years	15	30.6
>20 years	34	69.4
Sex Female	32	65.3
Male	17	34.7
Fluoride experience		
Only fluoride varnish	20	40.8
Only fluoride mouthwash	1	2.0
Experienced in both	3	6.1
No experience with both	25	51.1

Table 2. Bond failure probability in each group

	Brackets (n)	Failed brackets (n)	Failure proportion (%)
Randomized trial Group 1: intervention	482	7	1.5
Group 2: control	469	19	4.0
Total	951	26	2.7

Table 3. Bond failure in each area

	Number of bond failures
Upper	
Right posterior teeth	4
Right anterior teeth	0
Left anterior teeth	0
Left posterior teeth	7
Lower	
Right posterior teeth	6
Right anterior teeth	4
Left anterior teeth	4
Left posterior teeth	1

DISCUSSION

This study evaluated whether polishing with fluoride prophy paste prior to enamel pretreatment with orthophosphoric acid on bracket bonding and bond failure rates, finding that bond failure rates were significantly lower in Group 1 (fluoride prophy paste) than in Group 2 (non-fluoride prophy paste). The results demonstrated significantly lower bond-failure rates in the fluoride prophy paste group than in the non-fluoride prophy paste group. Therefore, the null hypothesis was rejected.

These findings differ from those of a previous study that reported a higher bond failure rate-of 8.0%-when brackets were bonded after fluoride polishing using SEP.[6] The overall proportion of bond failures in this study was substantially lower, at 2.7%, likely due to differences in the bonding protocol.

A conventional three-step bonding method, which consists of phosphoric acid etching, primer application, and curing of the resin composite were used. Previous research has suggested that this conventional method results in greater surface roughness and more pronounced enamel tags, leading to higher bond strength than SEP systems; it also leaves more residual adhesive on the enamel surface after debonding.[12] Therefore, although polishing with fluoride prophylaxis paste before bonding may reduce bond strength with SEP, the conventional method used in this study appeared to mitigate such adverse effects.

Bond failure was analyzed in relation to explanatory variables, including age, sex, prophy paste use, and prior fluoride exposure (fluoride varnish and fluoride mouthwash use). Based on the results of survival analysis, the use of fluoride prophy paste was associated with a statistically significant reduction in the risk of bond failure, lowering the hazard by approximately 74.2%. These findings contradict previous assertions that fluoridated abrasive pastes inhibit bracket bonding. In addition, age was also identified as an a significant predictor of bond failure. Younger individuals typically have softer enamel, whereas older individuals have harder enamel, which may affect bonding outcomes.[13] Studies have also reported that bond failure rates are higher in teenagers than in adults, primarily due to lower compliance with orthodontic instructions, thicker gingiva, ongoing tooth eruption, and oral habits.[14]

Table 4. Survival analysis results

	N	Failure number	Survival	Standard error	95% confidence interval	Logrank test
Randomized trial Group 1	482	7	0.985	0.00545	0.970-0.993	p=0.0146*
Group 2	469	19	0.959	0.00910	0.937-0.974	

*In the randomized trial, a significant difference (p<0.05) was detected between fluoride pumice polishing intervention and control groups.

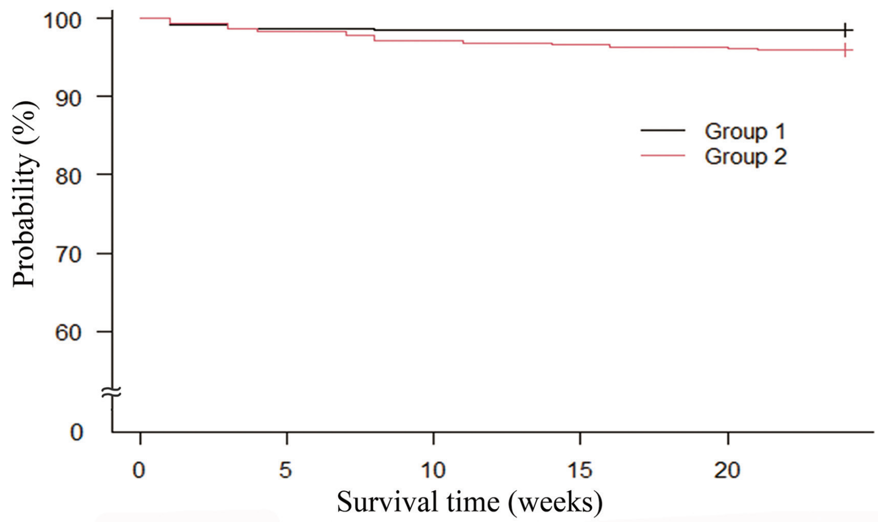

Figure 3. Kaplan-Meier survival curve depicting bracket survival times for each study group.

Table 5. Hazard rations for bracket failure using a frailty model

	Coef	Se (coef)	Exp (coef)	Chi-sq	DF	p
Prophy paste	-1.35515	0.47547	0.2579	8.12	1	0.0044
Sex	-0.13442	0.44731	0.8742	0.09	1	0.7600
Age	-0.08248	0.03542	0.9208	5.42	1	0.0200
Varnish	-0.35300	0.50545	0.7026	0.49	1	0.4800
Mouthwash	0.14653	0.77622	1.1578	0.04	1	0.8500
Frailty (patients)				0.00	0	0.8200

*In the prophy paste and age, a significant difference (p<0.05) was detected.

The participants were, therefore, categorized by age to account for these factors. Survival analysis showed that bond failure was significantly reduced in older individuals (coefficient =0.08). One explanation for the significantly lower failure rate observed with fluoride prophy paste compared with non-fluoride prophy paste is that 58% (11/19) of the individuals in the non-fluoride prophy paste group were teenagers. The age-related risk factors in these patients may have influenced the failure, rather than the fluoride itself.

Prior fluoride exposure was another key variable. Previous studies have suggested that enamel surfaces may be temporarily affected after APF treatment, and have recommended delaying bracket bonding for at least 21 days after APF application to allow the enamel to regain its original hardness.[10] In our study,15 bond failures were observed among the 470 brackets bonded to participants with prior fluoride exposure, corresponding to a failure rate of 2.7%. This finding implies that by the time brackets were bonded, the participants' enamel surfaces had returned to their original hardness, given that at least a few years had passed since their last fluoride treatment.

The locations where bond failures occurred were consistent with the findings of previous studies.[14,15] In the present study, bond failures occurred more frequently in the maxillary and mandibular molars and in the mandibular anterior teeth. This pattern may be attributed to the stronger biting forces applied to lower teeth during mastication and difficulty in maintaining moisture control in the maxillary molar region due to salivary gland activity.[16,17] Although bond failures are commonly reported to occur within the first month after bracket bonding,[15] bracket survival remained relatively stable during this period in both groups. Previous studies that using Kaplan-Meier survival analysis and log-rank tests to compare conventional adhesives with self-etching systems have reported conflicting findings. Ome authors observed lower survival rates with conventional adhesives,[18,19] whereas others reported superior long-term performance of conventional adhesives, particularly under conditions simulating clinical aging, such as thermal cycling.[20,21] The survival curves observed in the present study are consistent with these latter findings, exhibiting the relatively flat trajectory characteristic of conventional adhesives. Application of fluoride prophy paste did not appear to influence the survival curves, indicating that fluoride exposure had no significant effect on bracket adhesion when the conventional bonding protocol was used.

Study Limitations

This study had several limitations. First, the sample size was determined based on the number of brackets tested in Grover et al.,[2] who investigated the effect of fluoride varnish on bracket adhesion using SEP specifications and found that fluoride varnish resulted in a significantly higher rate of adhesion failure compared to pumice. In this study, because the analysis was based on the number of brackets rather than on the number of subjects, data were clustered by subject (per mouth) to account for potential heterogeneity. Nevertheless, the relatively small number of participants may have reduced the precision and generalizability of the findings.

Second, the generalizability of the results may be limited by a single-center design, which may not fully represent diverse patient populations or clinical settings. Surveys regarding fluoride varnish and mouthwash experience with may be limited by recall bias. Additionally, the use of multiple operators may have introduced inter-examiner variability. However, all operators were instructed on the bonding protocol prior to the commencement of the study. Furthermore, the follow-up period was limited to 6 months and may not fully reflect long-term bracket survival. Furthermore, the study evaluated only a conventional phosphoric acid etch-and-rinse bonding protocol and did not investigate alternative surface-conditioning methods, such as SEPs. Therefore, the findings cannot be generalized to all orthodontic bonding systems. Moreover, the choice of brackets and adhesives was limited to a single type, which may restrict the applicability of the results to other orthodontic materials. The potential effects of tooth-surface modification through polishing with fluoride or non-fluoride prophy pastes were not extensively evaluated, which may have affected the assessment of enamel surface changes and their influence on bonding.

CONCLUSION

This randomized trial evaluated bracket bonding to enamel surfaces briefly polished with fluoride-containing and fluoride-free prophy pastes, demonstrating that the bracket-bonding failure rate was significantly lower in the fluoride prophy paste group than in the non-fluoride prophy paste group. In addition, the failure rates were lower than those reported in some previous studies using conventional bonding protocols. The higher failure rate associated with non-fluoride prophy paste polishing may be attributed to age-related risk factors. The findings suggest that the use of fluoride-containing prophy paste before phosphoric acid etching does not adversely affect bracket bonding and may be associated with improved bracket survival when a conventional etch-and-rinse bonding protocol is used.

Ethics

Ethics Committee Approval: This study was approved by the Nihon University School of Dentistry Ethics Committee (approval number: EP22D014, date: 17.11.2024).

Informed Consent: All participants were informed about the study protocol and signed the consent form.

Footnotes

Author Contributions: Concept - K.H., Y.N., M.M.; Design - K.H., Y.N.; Data Collection and/or Processing - K.H., M.I., Y.U., Y.N.; Analysis and/or Interpretation - F.K., Y.K., Y.N.; Literature Search - K.H., M.I., Y.U., Y.N.; Writing - Y.N.

Conflict of Interest: No conflict of interest was declared by the authors.

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TURKISH JOURNAL OF ORTHODONTICS

Original Article

Cytotoxicity Assessment of the Effects of Pre-Orthodontic Trainer Appliances on Human Gingival Fibroblasts: An *in vitro* Study

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Main Points

- All 25 pre-orthodontic trainer appliances maintained cell viability above the ISO 10993-5 cytotoxicity threshold, indicating acceptable in vitro biocompatibility overall.
- Appliance-specific differences in cell viability were detected, although no statistically significant reductions were observed relative to the negative control.
- The K3 Blue (polyurethane/thermoplastic elastomer hybrid) appliance demonstrated the lowest cell viability and the most pronounced morphological alterations among the tested models.
- These findings emphasize the importance of appliance-level biocompatibility assessment, particularly for devices intended for prolonged intraoral use in children.

ABSTRACT

Objective: This study aimed to evaluate the *in vitro* cytotoxic effects of 25 pre-orthodontic trainer appliances on human gingival fibroblasts (HgnFs) using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay and morphological analysis.

Methods: Twenty-five pre-orthodontic trainer appliances were sterilized and incubated in Dulbecco's Modified Eagle Medium for 1 month to obtain conditioned eluates, in accordance with the principles of ISO 10993-5. The eluates were filtered and applied to cultured HgnFs for 48 h. Cell viability was assessed using the MTT assay, and morphological changes were evaluated using an inverted light microscope. Statistical analysis was performed at the appliance level using the Kruskal-Wallis test, followed by Dunn's post-hoc test ($p<0.05$).

Results: Statistically significant differences in cell viability were observed among the 25 appliance groups [Kruskal-Wallis H (25)=47.58, $p=0.004$]. The K3 Blue (A8) appliance demonstrated significantly lower viability than J2 (A12) and several other appliance models. Importantly, none of the tested appliances exhibited a statistically significant reduction in cell viability compared to the negative control group. All appliances maintained viability values above the ISO 10993-5 cytotoxicity threshold under the experimental conditions.

Conclusion: Within the limitations of this *in vitro* study, most pre-orthodontic trainer appliances demonstrated acceptable cytocompatibility with HgnFs. Appliance-specific differences were observed, highlighting the importance of individual appliance evaluation rather than broad material-based generalisations. Further studies incorporating long-term exposure models and in vivo validation are necessary.

Keywords: Pre-orthodontic trainer appliance, cytotoxicity, human gingival fibroblast, MTT assay, biocompatibility, myofunctional orthodontics

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INTRODUCTION

Craniofacial development and the aetiology of malocclusions are influenced by a complex interplay of genetic and environmental factors, including myofunctional habits. The significant impact of myofunctional habits on craniofacial development and malocclusion has been well documented for many years. There is a strong relationship between function and morphology, as the functions of chewing, speaking, breathing, and swallowing, together with the muscles of the jaw and face, directly influence dental, jaw, and facial development. Myofunctional treatment is an orthodontic method that aims to normalize impaired muscle and functional issues in the oral and jaw regions.[1]

The ideal breathing pathway is through the nose, which filters and humidifies air, ensuring better oxygenation when it reaches the lungs. For proper craniofacial development, the mouth should be closed, the teeth should be lightly in contact, and the tongue should rest against the palate. When the lip, cheek, and tongue muscles function correctly, jaw development is supported and the teeth can align physiologically. Mouth breathing, recognized since early years of orthodontics as a significant cause of malocclusion, leads to characteristic adaptations in affected individuals. Typically, the lips remain open, the tongue drops to a lower position, and abnormal swallowing patterns develop. These alterations disrupt the natural balance of forces on the teeth and jaws, resulting in various types of malocclusion classified as myofunctional disorders. Early treatment of these functional anomalies is crucial to prevent their progression into more severe morphological issues. The extent of craniofacial deformities due to habits depends on the nature of the movement, the magnitude of the force, and the duration and frequency of the habit.[2,3]

Pre-orthodontic trainer appliances are increasingly used for early intervention to address and correct harmful oral habits, guide favourable growth, and ensure adequate space for permanent teeth before more severe problems develop. The MYOBRACE® system (Myoresearch Co., Gold Coast, Queensland, Australia) is a widely utilized myofunctional appliance system designed to correct breathing disorders and myofunctional habits. These appliances are typically introduced in early childhood (aged 3-6 years) to promote desired craniofacial development, with usage protocols varying by appliance type, often including nightly wear and specified daytime hours of use.

The system comprises various series, including MYOBRACE® for Juniors (J1, J2, and J3), MYOBRACE® for Kids (K0, K1, K2, K3, K1 Broad, K2 Broad, and K3 Broad), MYOBRACE® for Teens (T1, T1 BWS, T2, T3, and T4), MYOBRACE® Interceptive Class III (i-3N, i-3, and i-3H), MYOBRACE® Permanent Dentition Class III (P-3N, P-3, and P-3H), and MYOBRACE® for Adults (A1, A2, and A3). Each series and model are designed with specific indications, functional features and usage protocols tailored to different age groups and malocclusion types.[4]

These appliances are typically manufactured from various polymeric materials such as silicone, polyurethane (PU), thermoplastic PU (TPU), and thermoplastic elastomers (TPE). Because these appliances remain in prolonged contact with oral tissues, their biocompatibility is paramount. Biomaterials are natural or synthetic substances used to perform or support the functions of living tissues in the human body. Due to their constant or intermittent contact with bodily fluids, these materials must possess specific properties such as mechanical strength, appropriate weight and density, wear resistance, suitability for mass production, aesthetic appeal, chemical stability, and fatigue resistance. Most importantly, biocompatibility, defined as the material's ability to interact with body tissues without causing harmful immunological or toxic reactions, is the primary criterion for patient safety, especially for orthodontic appliances intended for long-term use in the oral cavity. Silicone, for example, a polymer of silicon, is widely recognized for its high biocompatibility, flexibility and resistance to degradation.[5] Recent *in vitro* studies have specifically investigated the cytotoxic and biological effects of materials used in myofunctional and elastodontic appliances. Huang et al.[6] evaluated the biocompatibility and cytotoxic effects of myofunctional appliance materials on human periodontal ligament fibroblasts and reported material-dependent differences in cell viability and cellular morphology. Similarly, Dinu et al.[7] assessed the toxicological profile of elastodontic devices and demonstrated that material composition plays a critical role in the biological response of oral tissues. Despite their widespread use and long-term intraoral presence, limited literature exists on the cytotoxic effects of pre-orthodontic trainer appliances, particularly regarding the diverse range of materials and models currently available.

Therefore, the present study aimed to assess the *in vitro* cytotoxic effects of 25 pre-orthodontic trainer appliances on human gingival fibroblasts (HgnFs) using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay and morphological analysis in order to provide critical insights into their biocompatibility.

METHODS

This study was approved by the Biruni University Ethics Committee (approval number: BIAEK 2023/77-24, date: 06.01.2023).

Appliance Selection and Preparation

Twenty-five MYOBRACE® trainer models, representing various material categories including silicone, PU, TPU, TPE, and their combinations, were included in this study. No a priori power or sample size calculation was performed. The sample size was determined by the number of commercially available MYOBRACE® trainer models included in the system under investigation. Multiple technical replicates were used for each appliance to ensure experimental reliability. The specific models and their material compositions are detailed in Table 1.

Table 1. Myoresearch trainer appliances and their material compositions

Group	Model name	Material base
A1	A1	Silicone-based trainer
A2	i3-h	Polyurethane-based trainer
A3	A2	Silicone-based trainer
A4	P3	Polyurethane + thermoplastic elastomer-based
A5	T4B	Polyurethane-based trainer
A6	T4A	Polyurethane-based trainer
A7	i3-n	Silicone-based trainer
A8	K3 Blue	Polyurethane + thermoplastic elastomer-based
A9	T4K Soft Blue	Silicone-based trainer
A10	T4K Soft Pink	Thermoplastic elastomer-based trainer
A11	K1 Blue	Polyurethane-based trainer
A12	J2	Thermoplastic elastomer-based trainer
A13	K1 Clear	Polyurethane-based trainer
A14	T4A Hard Red	Silicone-based trainer
A15	TMD	Polyurethane-based trainer
A16	J1	Silicone-based trainer
A17	i3	Silicone + thermoplastic elastomer-based
A18	K3 Pink	Polyurethane + thermoplastic elastomer-based
A19	K2	Silicone + thermoplastic elastomer-based
A20	P3h	Polyurethane-based trainer
A21	Liptrainer	Silicone-based trainer
A22	K1 Pink	Silicone + thermoplastic elastomer-based
A23	Myochew	Silicone-based trainer
A24	Infant trainer	Silicone-based trainer
A25	T4A Clear	Polyurethane-based trainer

One representative material section was obtained from each trainer appliance. As some appliances consisted of multiple materials, the collected sections were intended to represent the combined material composition of each appliance, reflecting the clinical configuration rather than isolated materials. Sectioning was performed using a heavy-duty manual cutting instrument, and sample dimensions were standardized as far as possible (approximately 23×14 mm). No rotary instruments were used during sectioning to avoid heat generation or burr formation that could influence experimental outcomes.

All material sections were thoroughly cleaned under running water and subsequently sterilized using ultraviolet irradiation. After sterilization, the samples were handled under sterile conditions for eluate preparation.

Eluate Preparation

Each sterilized material section was placed in sterile 6-well culture plates. A fixed volume of Dulbecco's Modified Eagle Medium (DMEM), supplemented with 10% foetal bovine serum (FBS) and 1% antibiotic-anti-mycotic solution, was added to each well. The plates were incubated at 37 °C in a humidified atmosphere with 5% CO_2 for 1 month to allow the release of soluble components from the appliance materials.

This prolonged incubation period was selected to obtain eluates representative of cumulative material exposure over time, simulating long-term intraoral contact. Eluate preparation followed the general principles outlined in ISO 10993-5 and ISO 10993-12, without claiming full standardization of the surface area-to-volume ratio.

After incubation, the conditioned media (eluates) were collected and filtered through a 0.22-µm syringe filter to ensure sterility and remove particulate matter. Unconditioned DMEM served as the negative control.

Cell Culture

HgnFs were cultured in DMEM supplemented with 10% FBS, 100 U/mL penicillin, and 100 µg/mL streptomycin. The cells were maintained in a humidified incubator at 37 °C with 5% CO_2 and were harvested during the exponential growth phase for cytotoxicity experiments.

Cell Viability Assessment (MTT Assay)

HgnFs were seeded into 96-well microplates at a density of 2.0×10^4 cells/well and allowed to adhere for 24 h under standard culture conditions. After the attachment period, the culture medium was replaced with the prepared eluates or control medium, and the cells were exposed for 48 h.

Cell viability was assessed using the MTT assay. Following the exposure period, the eluates were removed and the cells were incubated with 100 µL of MTT solution (0.5 mg/mL in serum-free DMEM) for 4 h at 37 °C in the dark. The resulting formazan crystals were dissolved by adding 100 µL of dimethyl sulfoxide to each well. Absorbance was measured at 570 nm, with a reference wavelength of 630 nm, using a microplate reader. Cell viability was calculated as a percentage relative to the negative control group.

For each appliance-derived eluate, the MTT assay was performed using 12 technical replicates (wells) to minimize intra-assay variability. The mean absorbance of these technical replicates was calculated and used as a single data point representing that sample for statistical analysis.

Morphological Analysis

Following the 48-h exposure to the eluates, morphological changes in HgnFs were evaluated using an inverted light microscope (Nikon, Japan) at 20× magnification. Parameters such as cell detachment, membrane blebbing, cell shrinkage, and cytoplasmic granulation were qualitatively assessed and photographed.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Data distribution was evaluated using the Shapiro-Wilk test. As the data did not follow a normal distribution, non-parametric statistical tests were applied. Differences among groups were analysed using the Kruskal-Wallis H test, followed by Dunn's post-hoc test with Bonferroni correction when appropriate.

The statistical unit of analysis was the appliance (n=25). Repeated MTT measurements were treated as technical replicates and not considered independent observations. A p-value of <0.05 was considered statistically significant.

RESULTS

The cytotoxic effects of the 25 Myoresearch trainer appliances on HgnFs were evaluated using the MTT assay and morphological analysis. Cell viability was calculated as a percentage relative to the untreated control group.

Cell Viability Assessment (MTT Assay)

The MTT assay results indicated statistically significant differences in cell viability among the various appliance groups [Kruskal-Wallis H (25)=47.58, p=0.004]. A post-hoc comparison with the negative control group demonstrated that none of the 25 appliance groups showed a statistically significant reduction in cell viability compared with the negative control group. This finding indicates that all tested appliances maintained cell viability above the ISO 10993-5 cytotoxicity threshold under these *in vitro* conditions.

However, statistically significant differences were observed when specific trainer-appliance groups were compared. For each appliance, a single viability value was obtained by averaging 12 technical replicates, and appliance-level values (n=25) were used for statistical analysis. Median values and interquartile ranges for each trainer group and for the control are presented in Table 2. The distribution of viability measurements across all groups is illustrated in Figure 1, showing medians, interquartile ranges, and outliers.

Overall viability trends: Most silicone-based trainer appliances, including A1, A3, A7, A9, A14, A16, A21, A23, and A24, demonstrated high cell viability, with most measurements exceeding 90% (e.g., A16 [J1] showed a median viability of 99.8%). These findings indicate a favourable *in vitro* biocompatibility profile for silicone-containing appliances.

Mixed-material groups containing silicone components, such as A17(i3), A19 (K2), and A22 (K1 Pink), also exhibited high cell viability, generally comparable to that observed in predominantly silicone-based appliances.

Polyurethane and thermoplastic elastomers-based appliances: Trainer appliances primarily composed of PU or TPE, or combinations thereof, demonstrated greater variability in cell viability results.

The K3 Blue (A8) group, composed of PU and thermoplastic elastomer, consistently exhibited the lowest cell viability among all tested appliances. Specifically, K3 Blue (A8) showed significantly lower viability compared with J2 (A12) (p<0.05) and with several silicone-based appliances (including A1, A3, A7, A9, A14, A16, A21, A23 and A24) (all p<0.05).

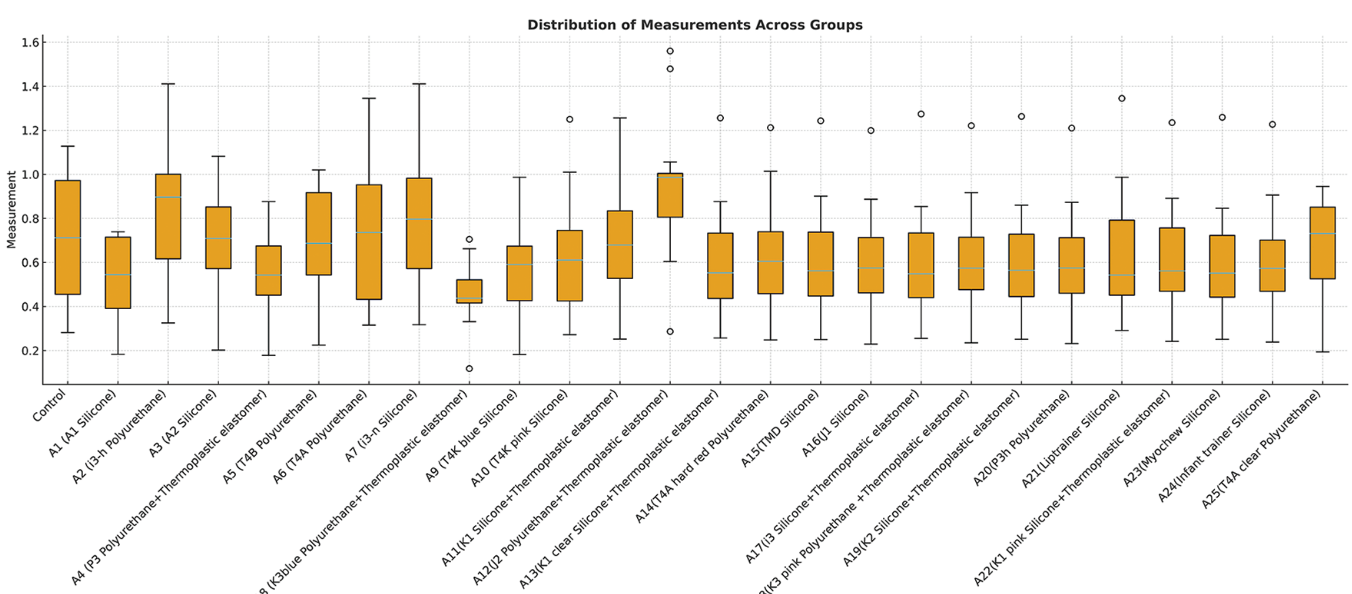

Figure 1. Box-and-whisker plots illustrating the distribution of cell viability values of human gingival fibroblasts following 48 h of exposure to 1-month-conditioned eluates obtained from 25 different myofunctional trainer appliances. Boxes represent the median and interquartile range,whiskers indicate minimum and maximum values, and dots represent outliers. Data are presented at the appliance level (n=25), with each value derived from the mean of 12 technical replicates.

Table 2. Median cell viability values (percentage of control) of human gingival fibroblasts (HgnFs) after 48 hours of exposure to 1-month-conditioned eluates obtained from 25 different myofunctional trainer appliances

Group	Model name & material base	Median absorbance (OD 570 nm)	Median cell viability (%) relative to control
Control	-	0.74	100.0
A1	A1 Silicone	0.51	68.9
A2	i3-h Polyurethane	0.89	120.3
A3	A2 Silicone	0.74	100.0
A4	P3 Polyurethane + thermoplastic elastomer	0.60	81.1
A5	T4B polyurethane	0.72	97.3
A6	T4A polyurethane	0.77	104.1
A7	i3-n Silicone	0.83	112.2
A8	K3 Blue polyurethane + thermoplastic elastomer	0.49	66.2
A9	T4K Soft Blue silicone	0.59	79.7
A10	T4K Soft Pink thermoplastic elastomer	0.66	89.2
A11	K1 Blue polyurethane	0.73	98.6
A12	J2 thermoplastic elastomer	0.99	133.8
A13	K1 Clear polyurethane	0.64	86.5
A14	T4A Hard Red silicone	0.67	90.5
A15	TMD polyurethane	0.65	87.8
A16	J1 Silicone	0.65	87.8
A17	i3 silicone + thermoplastic elastomer	0.64	86.5
A18	K3 Pink polyurethane + thermoplastic elastomer	0.65	87.8
A19	K2 Silicone + thermoplastic elastomer	0.65	87.8
A20	P3h polyurethane	0.65	87.8
A21	Liptrainer silicone	0.67	90.5
A22	K1 Pink silicone + thermoplastic elastomer	0.65	87.8
A23	Myochew silicone	0.64	86.5
A24	Infant Trainer silicone	0.65	87.8
A25	T4A Clear polyurethane	0.76	102.7

Each value represents one appliance (n=25) and was calculated as the mean of 12 technical replicates derived from the same eluate. Statistical comparisons were performed at the appliance level.

Other PU-based trainers, such as A2 (i3-h), A5 (T4B), A6 (T4A), A11 (K1 Blue), A13 (K1 Clear), A15 (TMD), A20 (P3h), and A25 (T4A Clear), generally demonstrated acceptable cell viability values. Although some of these appliances showed lower median viability values than silicone-based groups (e.g., approximately 85% for A6 and 88% for A20), these differences were not statistically significant compared with the control group.

Thermoplastic elastomer-based trainers, such as A10 (T4K Soft Pink) and A12 (J2), demonstrated acceptable cell viability, with A12 (J2) showing one of the highest viability values among the non-silicone groups.

Specific group comparisons: Statistical analysis confirmed that the viability of the K3 Blue (A8) group was significantly lower than that of multiple silicone-based appliances and selected TPE-based groups. In contrast, no statistically significant differences were observed among the silicone-based appliances themselves, indicating a consistently favourable biocompatibility profile within this subgroup.

Morphological Analysis

Microscopic examination of HgnFs following 48 h of exposure to 1-month-conditioned eluates provided qualitative findings that were consistent with the MTT assay results.

Control group: Cells exhibited normal spindle-shaped morphology, intact cell membranes, and confluent growth, indicative of healthy fibroblast proliferation.

Silicone-based groups: Cells exposed to eluates from silicone-based appliances generally maintained a healthy morphology, comparable to that observed in the control group. No marked morphological alterations, such as extensive cell detachment, membrane blebbing or pronounced cytoplasmic granulation, were observed.

Polyurethane and thermoplastic elastomer-based groups: Cells exposed to eluates from most PU- and TPE-based appliances exhibited minor to moderate morphological changes, including slight alterations in cell shape or reduced cell density; however, overall cellular integrity was preserved.

In contrast, cells exposed to eluates from the K3 Blue (A8) appliance displayed more pronounced morphological alterations. These changes included cell shrinkage, reduced substrate adherence, partial cell rounding, cytoplasmic granulation, and occasional membrane blebbing, indicating a stronger cellular response compared with other groups.

Overall, the morphological observations corroborated the quantitative MTT findings, demonstrating acceptable *in vitro* biocompatibility for all tested appliances and highlighting K3 Blue (A8) as the appliance associated with the most pronounced reduction in cell viability and morphological integrity.

DISCUSSION

The biocompatibility of materials used in pre-orthodontic trainer appliances is of critical importance because of their prolonged contact with oral soft tissues, particularly in growing children. This study evaluated the *in vitro* cytotoxic effects of 25 Myoresearch trainer appliances on HgnFs, providing insight into their biological response under controlled experimental conditions. Overall, the findings indicate that most of the evaluated appliances demonstrate acceptable cytocompatibility with HgnFs, which are consistent with their intended clinical use. The MTT assay, a widely accepted method for assessing cellular metabolic activity and viability, revealed that, although overall cytotoxicity was low, certain appliance models exhibited statistically significant differences in cytotoxicity.

A key observation in this study was that several silicone-containing trainer appliances (e.g., A3, A7, A9, A14, A16, A21, A23, and A24) demonstrated high cell viability and preserved cellular morphology, with values approaching those of the untreated control group. These findings are in agreement with previous reports describing the favourable biocompatibility profile of silicone-based materials in biomedical and dental applications.[8,9] Similarly, some mixed-material appliances incorporating silicone components (e.g., A17, A19, and A22) exhibited high viability, suggesting that the presence of silicone may contribute positively to the overall biological response of these appliances. Nevertheless, biocompatibility outcomes in the present study were evaluated at the appliance level, and the findings should not be interpreted as definitive evidence of the intrinsic superiority of any single material type.

In contrast, appliances primarily composed of PU- or PU-based hybrid materials exhibited variable cellular responses. Among these appliances, K3 Blue (A8) consistently demonstrated the lowest cell viability and more pronounced morphological alterations compared with several other models. This observation is consistent with previous studies reporting that certain thermoplastic and PU-based orthodontic materials may induce variable cytotoxic responses depending on their formulation and processing methods.[10-12] The reduced cell viability observed for this specific appliance may be associated with the release of residual monomers, oligomers, or degradation products from the polymer matrix, as well as manufacturing-related factors such as thermoforming or curing conditions.[13,14] Nevertheless, because the present study did not include chemical characterization of the eluates, no definitive conclusions can be drawn regarding the specific causative compounds. These findings are also consistent with recent *in vitro* studies evaluating the biocompatibility of myofunctional and elastodontic appliances. Huang et al.[6] reported variable cytotoxic responses among different myofunctional appliance materials when tested on human periodontal ligament fibroblasts, emphasizing that biological effects might differ substantially between appliance models despite similar clinical indications. Similarly, Dinu et al.[7] demonstrated that elastodontic devices exhibit material-dependent biological responses, highlighting the influence of polymer composition and manufacturing processes on cytotoxicity outcomes. In agreement with these studies, the present findings support the concept that appliance-specific characteristics, rather than broad material classifications alone, play a critical role in determining *in vitro* biocompatibility.

Despite the statistically significant differences observed among certain appliance models, most tested appliances did not show a significant reduction in cell viability compared with the control medium. This finding suggests that under the experimental conditions applied, the majority of pre-orthodontic trainer appliances exhibit acceptable short-term *in vitro* cytocompatibility. However, the detection of reduced viability and morphological alterations in specific models highlights the importance of appliance-specific evaluation rather than broad, material-based generalizations, particularly when these devices are intended children with developing oral tissues.

Myofunctional trainer appliances, including the MYOBRACE® system evaluated in this study, play an important role in early orthodontic intervention.[15] Their clinical effectiveness depends not only on their functional and mechanical properties but also on their biological safety during prolonged intraoral contact.[16] While the present *in vitro* findings provide valuable preliminary information, the oral environment is highly dynamic, and factors such as salivary flow, enzymatic activity, pH fluctuations, temperature changes and mechanical loading may influence material behaviour and biological responses *in vivo*.[17]

From a materials science perspective, the relatively favourable cellular response observed in silicone-based appliances may reflect the principle that materials exhibiting high chemical stability and resistance to degradation tend to elicit fewer adverse biological reactions. In the context of long-term tissue contact, biocompatibility has traditionally been linked to the concept of chemical and biological inertness and the minimization of degradation products that may elicit inflammatory or cytotoxic responses.[13,14] Silicone polymers have historically been grouped among materials that are relatively resistant to degradation and are used in implantable medical devices. These considerations may partly explain the higher cell viability observed in silicone-containing appliances in this study, although biocompatibility remains dependent on specific formulations and processing characteristics.

Study Limitations

Several limitations of this study should be acknowledged. As an *in vitro* investigation, the experimental conditions cannot fully replicate the complex and dynamic environment of the oral cavity. Additionally, the study focused on overall cell viability and morphological changes, and did not include chemical analysis of eluates, which would be necessary to identify specific compounds responsible for the observed biological effects. Cytotoxicity was assessed following a 48-h exposure period, and longer-term or repeated exposures may yield different cellular responses. Furthermore, only HgnFs were evaluated; inclusion of additional oral cell types or in vivo studies would provide a more comprehensive understanding of biological safety.

CONCLUSION

Within the limitations of this *in vitro* study, most evaluated MYOBRACE® trainer appliances demonstrated acceptable cytocompatibility with HgnFs. However, certain appliance models incorporating PU-based hybrid materials, particularly K3 Blue (A8), exhibited reduced cell viability and discernible morphological changes.

These findings emphasize the importance of appliance-specific biocompatibility assessment and suggest that material composition and manufacturing characteristics should be carefully considered when selecting myofunctional trainer appliances for clinical use, especially in paediatric patients.

Further studies incorporating chemical characterization of eluates, long-term exposure models, additional cell types, and in vivo validation are warranted to better elucidate the biological behaviour and clinical safety of these widely used orthodontic devices.

Ethics

Ethics Committee Approval: This study was approved by the Biruni University Ethics Committee (approval number: BIAEK 2023/77-24, date: 06.01.2023).

Informed Consent: Not applicable (*in vitro* study).

Footnotes

Author Contributions: Concept - Z.M.T., M.G.; Design - Z.M.T., M.G.; Data Collection and/or Processing - Z.M.T.; Analysis and/or Interpretation - Z.M.T., H.G.G., M.G.; Literature Search - H.G.G.; Writing - Z.M.T., H.G.G.

Conflict of Interest: No conflict of interest was declared by the authors.

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TURKISH JOURNAL OF
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Original Article

A Bibliometric Assessment of the Turkish Journal of Orthodontics after WoS Indexing

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Main Points

- Since being indexed in 2017, the Turkish Journal of Orthodontics has maintained a steady output of publications (n=244) and an increasing number of citations, yielding an h-index of 15 and 5.77 citations per article.
- While case reports remained an accepted article type, no case reports were published after the third quarter of 2022, whereas systematic reviews became more frequent from the first quarter of 2023.
- Publications span 39 countries with; Türkiye and India the leading readers and cross regional collaboration hubs have expanded.
- Co-occurrence mapping highlights a growing focus on clear aligners, digital workflows, and artificial intelligence alongside conventional topics.
- Authorship is highly collaborative (94.7% multi-authored) and exhibits near gender parity.

ABSTRACT

Objective: This study analyzed the publication characteristics, citation patterns, and research trends of the Turkish Journal of Orthodontics (TJO) since its Web of Science (WoS) indexing in 2017.

Methods: A retrospective bibliometric analysis was conducted using data from the WoS Core Collection (2018-24) on April, 2025. Network analysis was performed using CiteSpace 6.3.R1 and VOSviewer 1.6.18. Descriptive statistics were used to analyze publication trends, authorship patterns, geographical distribution, and citation performance.

Results: A total of 244 publications were analyzed, comprising 192 (78.7%) original articles, 27 (11.1%) reviews, eight (3.3%) systematic reviews, and 17 (7.0%) case reports. The journal achieved an h-index of 15, with 1408 total citations and an average of 5.77 citations per article. Türkiye contributed the most publications (58.2%), followed by India (16.8%), the USA (6.6%), and Iran (5.3%). International collaboration involved 39 countries, and the most-cited article received 32 citations. The gender distribution of authorship was closely balanced: 52.2% female and 47.8% male. 94.7% of publications were multi-authored, with an average of 3.5 authors per article. Keyword analysis revealed thematic clusters dominated by clear aligners, malocclusion, cone-beam computed tomography, and dental materials.

Conclusion: TJO shows consistent growth in publication volume, expansion of international collaboration, and increases in citation impact since WoS indexing. The journal successfully captures emerging trends in clear aligners and rapid maxillary expansion while maintaining coverage of fundamental orthodontic topics. A strategic editorial evolution toward systematic reviews indicates a commitment to evidence-based practice. This bibliometric overview offers a data-driven foundation for future editorial decision-making and monitoring the journal's evolving role within orthodontic research.

Keywords: Abstracting and indexing, bibliometrics, journal impact factor, orthodontics, periodical

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INTRODUCTION

Scientific journals play a key role in sharing research and advancing science. The Turkish Journal of Orthodontics (TJO), the official publication of the Turkish Orthodontic Society, is a scientific, open-access periodical published quarterly in March, June, September, and December.[1] Since its inception in January 1988, TJO has supported the development of orthodontic science and practice, becoming a respected journal for publishing high-quality and ethically conducted research, clinical studies, and reviews.

A major milestone for the journal was its inclusion in the Web of Science (WoS) in 2017, which greatly increased its international visibility and academic impact. The WoS is a database owned by Clarivate Analytics and is a leading multidisciplinary bibliographic platform that indexes high-quality scientific journals and is widely used to measure research visibility and credibility.[2,3]

Bibliometric analysis is a quantitative method used to evaluate scientific literature and measure a journal's scholarly influence. The analysis provides insights into research growth, development, and collaboration patterns.[4-9] Bibliometric methodologies are generally divided into two complementary analytical dimensions: performance analysis and science mapping. Performance analysis evaluates the productivity and influence of research constituents, such as authors, institutions, and countries, whereas science mapping examines the intellectual and collaborative relationships among these constituents to reveal the structural and thematic evolution of a discipline.[5,6]

Given TJO's evolving position in orthodontic research following WoS indexing, a comprehensive bibliometric analysis can help reveal its academic impact, contributions, and connections within the global research community. Therefore, this study aimed to systematically evaluate TJO's publication characteristics, citation performance, authorship patterns, geographical distribution, institutional collaborations, and thematic evolution since its WoS indexing in 2017 and to provide a comprehensive understanding of the journal's impact on orthodontic research.

METHODS

Study Design and Search Strategy

This retrospective, observational study used bibliometric analysis to evaluate TJO's academic performance after its indexing in the WoS database.

The methodological framework of this study was guided by the dual-dimensional model proposed by Donthu et al.,[5] which categorizes bibliometric analyses into two complementary approaches: performance analysis and science mapping. Performance analysis was used to assess publication productivity, authorship characteristics, institutional and country-level contributions, and citation impact. Science mapping techniques were used to visualize and interpret the intellectual, thematic, and collaborative structures within the TJO research network, including co-authorship, co-citation, and keyword co-occurrence patterns.

All data were retrieved from the Clarivate Analytics WoS Core Collection (WoSCC) (webofscience.com). In the "Documents" section, the journal name "Turkish Journal of Orthodontics" was entered into the "Publication Titles" field, and a comprehensive search was performed in April 2025.

The initial search yielded 547 records. After the duplicate records were removed, the remaining records were subsequently filtered by "Publication Years," limiting the results to 2018-24. The analysis focused on complete annual data through December 2024, excluding 2025 publications to ensure sufficient citation accumulation time, resulting in 257 records. The document type was further restricted to include only case reports, articles, and review articles, resulting in a final dataset of 244 records after excluding one retracted case report from 2019 (Figure 1). Publications were exported in "plain text" format as full records and references from the WoSCC.

Data Collection and Classification

Data were manually retrieved from the journal's official website. Each article was individually reviewed by the same researcher (A.A.) and systematically classified according to multiple parameters: publication year, study type (e.g., original research, case report, etc.), keywords, funding status, number of authors, authors' gender, institutional affiliation and department of all authors, including the first author, and the academic or non-academic nature of affiliations. Author gender was determined based on the given names and, where necessary, publicly available institutional information. Affiliations were categorized by institution type (e.g., university, private practice, etc.) and departmental origin (e.g., orthodontics, prosthodontics, etc.). Following manual data curation, the authors systematically identified the research types and assigned each work to its relevant scientific domain through article-by-article screening conducted directly on the journal's official website.

Bibliometric Analysis Tools

VOSviewer (version 1.6.18, Leiden University, Netherlands) was used to perform collaboration network analysis (e.g., countries, institutions, and authors) and to generate keyword co-occurrence visualizations.[10] The LinLog/modularity method was used in VOSviewer to optimize network layouts.

CiteSpace (v6.3.R1 Advanced, Philadelphia, USA) was used to analyze co-citation and collaboration networks with 1-year time slices (i.e., G-index k=25, top n=50).[11] Tree-ring histories and cluster views were generated, and networks were pruned using sliced-network pruning and minimum spanning tree algorithms.

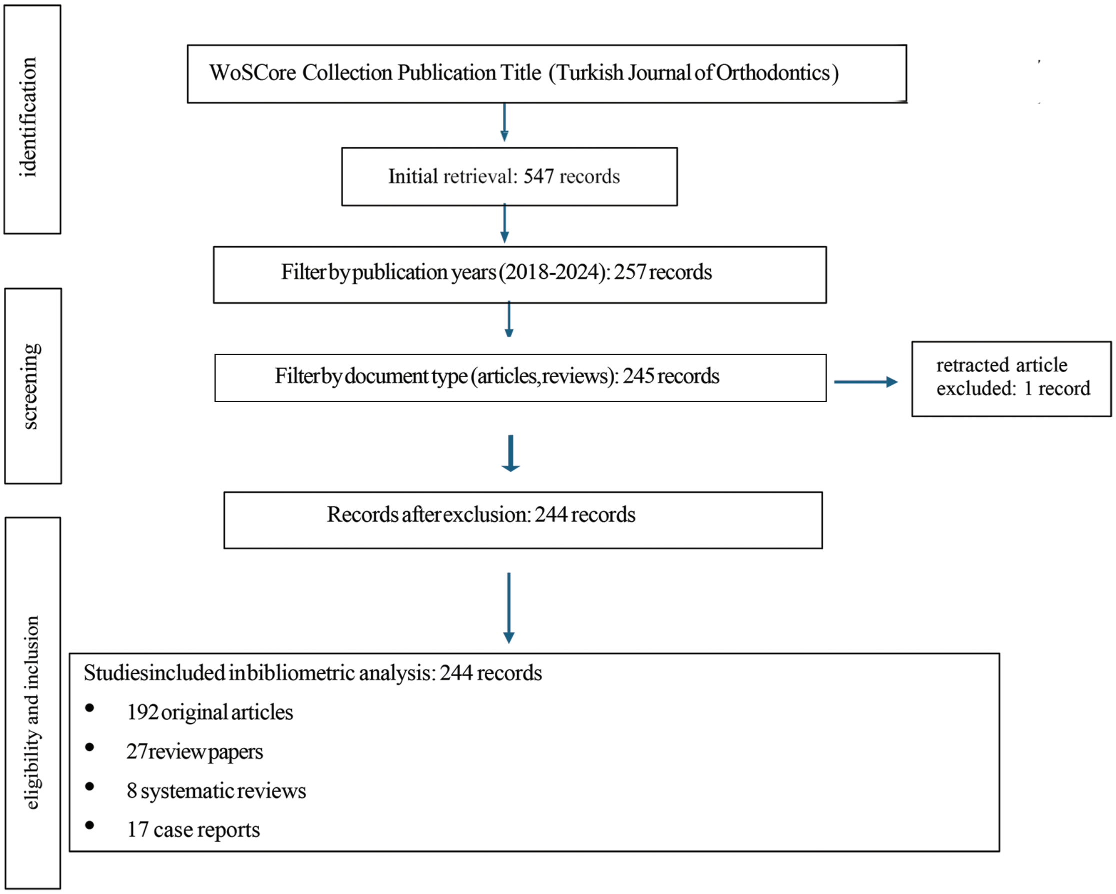

Figure 1. Study selection process following PRISMA guidelines.

Interpretation of Visulizations

The cluster view was used to identify the co-citation, co-authorship, and keyword co-occurrence patterns, facilitating the detection of major research themes and their relationships. Tree-ring history was used to visualize the temporal evolution of nodes such as authors, institutions, countries, or keywords. Betweenness centrality was used to measure how often a node lies on the shortest paths between other nodes, reflecting its role as a connector.

Statistical Analysis

Descriptive statistics were used (e.g., counts and percentages). No hypothesis testing was undertaken because the unit of analysis was the entire WoS-indexed population.

RESULTS

Performance Analysis

Publication trends

A total of 257 documents related to TJO were identified in the WoSCC between 2018 and 2024. Following search refinement to include only articles and review articles (245 records) and exclusion of one retracted case report from 2019, the final dataset comprised 244 publications; consisting of 192 (78.7%) original articles, 27 (11.06%) review papers, eight (3.28%) systematic reviews, and 17 (6.97%) case reports.

From 2018 to 2024, TJO published 244 articles, and one case report was retracted. Annual publication output by year was: 21 (2018); 40 (2019 and 2022); 34 (2020); 33 (2021); 37 (2023); and 36 (2024). Original articles consistently predominated. Case reports were published through the third quarter of 2022, with a peak of seven reports in 2019; none were published thereafter. Systematic reviews were first included in 2023, whereas review articles were published regularly throughout the study period.

Study methodologies

Methodological analysis revealed that 128 (52.5%) publications were clinical studies; of these, 80 (32.8%) were observational and 48 (19.7%) were interventional designs. Laboratory-based studies accounted for 28 (11.5%) of the publications, while a further 88 (36.0%) comprised non-patient-based research, including finite element method analyses, healthcare professional surveys, and bibliometric investigations.

Citation performance and impact

Although the number of publications has remained constant, citation analysis has shown an upward trend. Articles published in 2018 gradually accumulated citations, which peaked in subsequent years. The 2019 cohort, which represented the highest publication volume, showed strong citation growth, particularly from 2022 onwards.

Publications from 2020 to 2022 continued to receive citations, while articles from 2023 and 2024 began to accrue citations shortly after publication. Total citations exceeded 300 by 2024.

Years with higher publication volumes (e.g., 2019 and 2022) did not correspond to proportionally higher citation counts in those years. Instead, the highest citation counts were recorded in 2023-24, reflecting cumulative recognition of articles published in previous years. This finding indicates a temporal lag between publication and peak citation, consistent with patterns of citation maturation in scientific literature.

The analyzed publications received citations from 1309 articles, totaling 1408 citations. Excluding self-citations, 1282 unique citing articles accounted for 1376 citations. The average citation rate was 5.77 per article.

During the study period, TJO achieved an h-index of 15, indicating that 15 papers were cited at least 15 times. Additional metrics included a Clarivate 5-year impact factor of 1.5 and a Scopus CiteScore of 2.0. All records were indexed as "Dentistry Oral Surgery Medicine" in the Emerging Sources Citation Index.

Most frequently cited articles

The top ten most cited articles are presented in Table 1. The most cited publication was "Orthodontic Treatment with Clear Aligners and the Scientific Reality Behind Their Marketing: A Literature Review" by Tamer (2019), with 92 citations (11.5 per year). This was followed by "Assessment of Reliability of YouTube Videos on Orthodontics" by Kilinc (2019), with 62 citations (7.75 per year), and "Fixed Orthodontic Retainers: A Review" by Kaya (2019), with 50 citations (6.25 per year). Other highly cited publications included "Web-based Fully Automated Cephalometric Analysis" by Meric (2020) with 48 citations (6.86 per year) and "The Prevalence of Cleft Lip and Palate Patients: A Single-Center Experience for 17 Years" by Yilmaz (2019) with 42 citations (5.25 per year). Articles focusing on digital orthodontics, online health information, and emerging technologies; such as three-dimensional imaging, digital content reliability, microbial colonization, and 3D printing, also appeared among the most cited works, with citation counts ranging from 20 to 32.

Table 1. The top ten high impact articles published by TJO between 2017 and 2025

Title	Corresponding author	Publication year	Total citations	Average per year	2017	2018	2019	2020	2021	2022	2023	2024	2025
Orthodontic Treatment with Clear Aligners and The Scientific Reality Behind Their Marketing: A Literature Review	Tamer	2019	92	11.5	0	0	0	2	5	14	15	31	24
Assessment of Reliability of YouTube Videos on Orthodontics	Kilinc	2019	62	7.75	0	0	0	3	9	13	15	11	10
Fixed Orthodontic Retainers: A Review	Kaya	2019	50	6.25	0	0	0	3	0	11	16	10	10
Web-based Fully Automated Cephalometric Analysis: Comparisons between App-aided, Computerized, and Manual Tracings	Meric	2020	48	6.86	0	0	0	0	1	8	15	10	12
The Prevalence of Cleft Lip and Palate Patients: A Single-Center Experience for 17 Years	Yilmaz	2019	42	5.25	0	0	0	3	8	7	5	6	8

Table 1. Continued

Title	Corresponding author	Publication year	Total citations	Average per year	2017	2018	2019	2020	2021	2022	2023	2024	2025
Three-Dimensional Imaging in Orthodontics	Erten	2018	32	3.56	0	0	1	5	4	5	4	6	7
Evaluation of Internet Information about Lingual Orthodontics Using DISCERN and JAMA Tools	Olkun	2018	27	3	0	0	2	3	3	7	4	3	5
Microbial Colonization on Elastomeric Ligatures during Orthodontic Therapeutics: An Overview	Sawhney	2018	24	2.67	0	0	2	3	6	4	3	6	0
Directly Printed Aligner: Aligning with the Future	Panayi	2023	21	5.25	0	0	0	0	0	0	0	15	6
The Use of 3D Printers in Orthodontics-A Narrative Review	Ergul	2023	20	5	0	0	0	0	0	0	1	6	12

TJO, Turkish Journal of Orthodontics.

Authorship and collaboration patterns

A total of 851 authors contributed to the 244 publications included in this analysis, with an average of 3.5 authors per article. The average number of authors per article is a key bibliometric indicator used to assess the collaborative nature of scientific production; it is calculated using the formula: average number of authors=total number of authors/total number of articles.

Multi-authored papers comprised 94.7% of the total output (n=231), with the remaining 13 (5.3%) papers being single-authored. Gender-based authorship analysis revealed a balanced distribution. Overall, 444 (52.2%) female and 407 (47.8%) male authors were identified. Among the first authors, 134 (54.9%) were female and 109 (45.1%) were male.

Evaluation of institutional affiliations showed that 786 authors (92.4%) were affiliated with academic institutions, while 65 authors (7.6%) were affiliated with non-academic sectors, such as private practice or independent research organizations. Most contributors were from orthodontics, followed by prosthodontics, pediatric dentistry, and biostatistics.

The co-authorship network showed strong collaboration among researchers. Each node represents an author, with its size indicating the number of publications. Links between nodes represent co-authorship relationships, and color gradients show the average publication year. Many authors collaborated within the same institutions, while inter-institutional and international partnerships increased over time. Several active collaboration groups led by authors including Altug A.T., Arslan C., Ozdemir F., and Cesur E. were identified (Figure 2).

Multidisciplinary contributions

The journal included contributions from 26 disciplines beyond orthodontics, including anatomy; biomaterials and tissue engineering; bioengineering; pharmacology; otorhinolaryngology; psychology; biostatistics; microbiology; biotechnology; computer engineering; molecular biology; medical biochemistry; plastic surgery; physiology; child and adolescent psychiatry; developmental sciences; histology; occupational health; nuclear medicine; pathology; chemistry; general surgery; medical biology and genetics; and orthopedics.

Institutional and country-level contributions

Publications in the TJO between 2018 and 2024 originated from 39 different countries. The highest contributions were from Türkiye (n=37) and Türkiye (n=105), totalling 142 and representing 58.2% of all publications. The next-highest contributions were from India (n=41, 16.8%), the United States (n=16, 6.6%), and Iran (n=13, 5.3%). Additional contributions were recorded from Brazil (n=9); Italy (n=5); Cyprus, Egypt, Greece, Iraq, Saudi Arabia, Sweden, and Switzerland (each n=3); and Australia, Canada, and Malaysia (each n=2). Single-country contributions (n=1) included Austria, Azerbaijan, Cambodia, Denmark, England, Japan, Kuwait, Lebanon, Lithuania, Malta, Morocco, Nigeria, Pakistan, the People's Republic of China, Peru, Portugal, Scotland, Serbia, South Africa, Syria, the United Arab Emirates, South Korea, and Palestine. The geographical distribution of contributing countries is shown in Figure 3a.

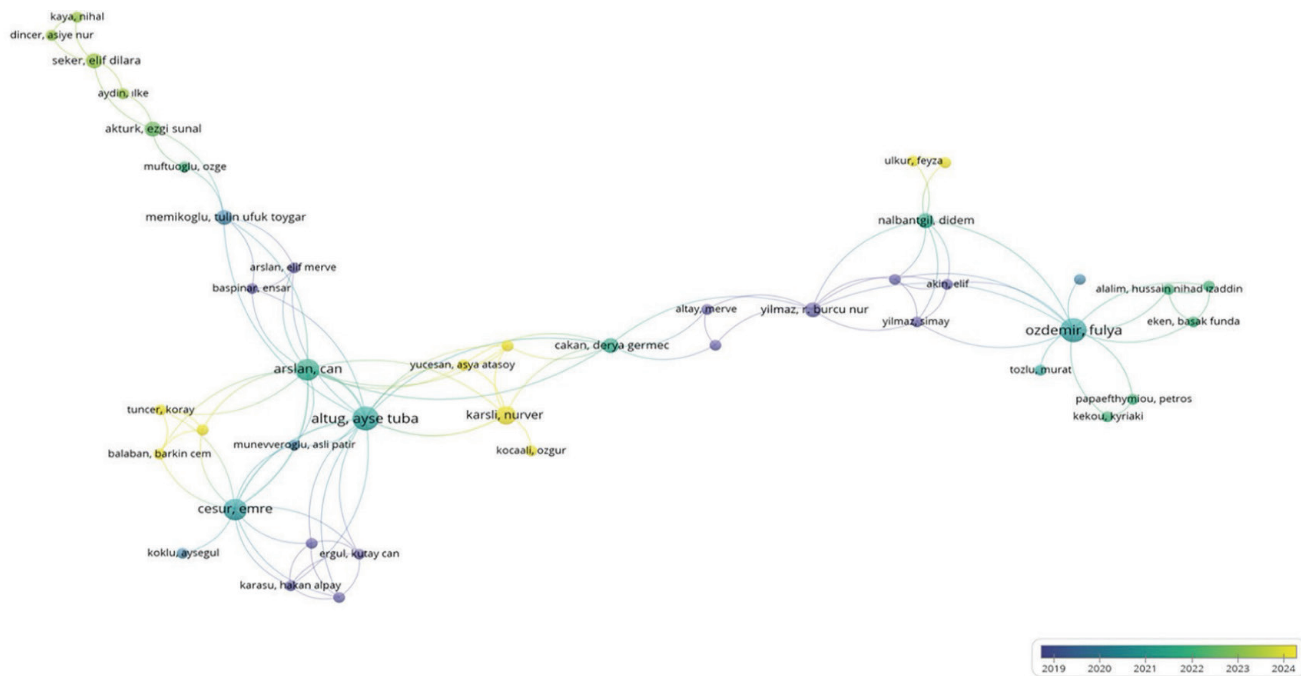

Figure 2. Co-authorship network analysis of publications in Turkish Journal of Orthodontics. Network visualization shows collaboration patterns among authors who published in TJO during the study period. Each node represents an author, with node size proportional to the number of publications. Edges (connections) between nodes indicate co-authorship relationships. Node colors indicate publication years according to the timeline shown in the bottom right corner, with a gradient shifting from purple to yellow-green. Larger nodes and multiple connections indicate authors with higher productivity and more extensive collaborative networks. The network identifies key research clusters and highlights the multidisciplinary collaborative nature of orthodontic research published in TJO. The visualization was generated using VOSviewer software. TJO, Turkish Journal of Orthodontics.

Collaboration network analysis identified Türkiye as the central hub of international partnerships, followed by India and the United States (Figure 3b). Strong collaborative links were observed between Türkiye and each of the following countries: India, the USA, and Switzerland. Additional cross-national partnerships included Canada, Iran, Serbia, Malaysia, Sweden, the UK, and Italy. Between 2018 and 2024, Türkiye and India experienced the most notable growth in publication output.

At the institutional level, Marmara University (n=15), Yeditepe University (n=13), Başkent University (n=11), and İstanbul Medipol University (n=11) published the most studies, followed by Ankara University (n=10), Bezmialem Vakıf University (n=9), and Istanbul University (n=8). The institutional collaboration network presented in Figure 4 shows that Atatürk University has the highest betweenness centrality, indicating that it plays a key bridging role by connecting otherwise weakly linked institutional clusters within the network. Other institutions, such as Marmara University and Yeditepe University, showed high publication volume but low centrality, reflecting localized research collaboration patterns.

Research topics

The WoS citation-topic analysis revealed that 199 (81.6%) publications were classified as "Dentistry & Oral Medicine". Additional topics included "Health Literacy & Telemedicine" (n=9, 3.7%), "Sleep Science & Circadian Systems" (n=7, 2.9%), and various interdisciplinary fields, including virology, psychiatry, laser therapy, and oncology (collectively 12.3%), highlighting TJO's multidisciplinary scope.

At the micro level, orthodontic treatment was the dominant topic, with 138 publications (56.6%), followed by dentin (n=23, 9.4%), dental regeneration (n=11, 4.5%), digital health literacy (n=9, 3.7%), and the temporomandibular disorders (n=9, 3.7%). Other notable topics included obstructive sleep apnea and periodontal microbiome (2.9% each), and cleft lip and palate (2.5%).

Funding and research support

The analysis revealed that 17 (7.0%) studies received support from national institutions, while 13 (5.3%) were funded by international organizations. Most publications (211 studies, 86.5%) did not report external funding sources.

Science Mapping

Citation and co-citation networks

Citation and co-citation analyses were conducted to identify the core intellectual structure of the TJO publications between 2018 and 2024 and the most influential journals cited by these publications (Figure 5). Among the cited journals, the American Journal of Orthodontics and Dentofacial Orthopedics had the highest co-citation frequency, followed by The Angle Orthodontist, European Journal of Orthodontics, and Dental Press Journal of Orthodontics. These journals occupied central positions within the network and formed the primary

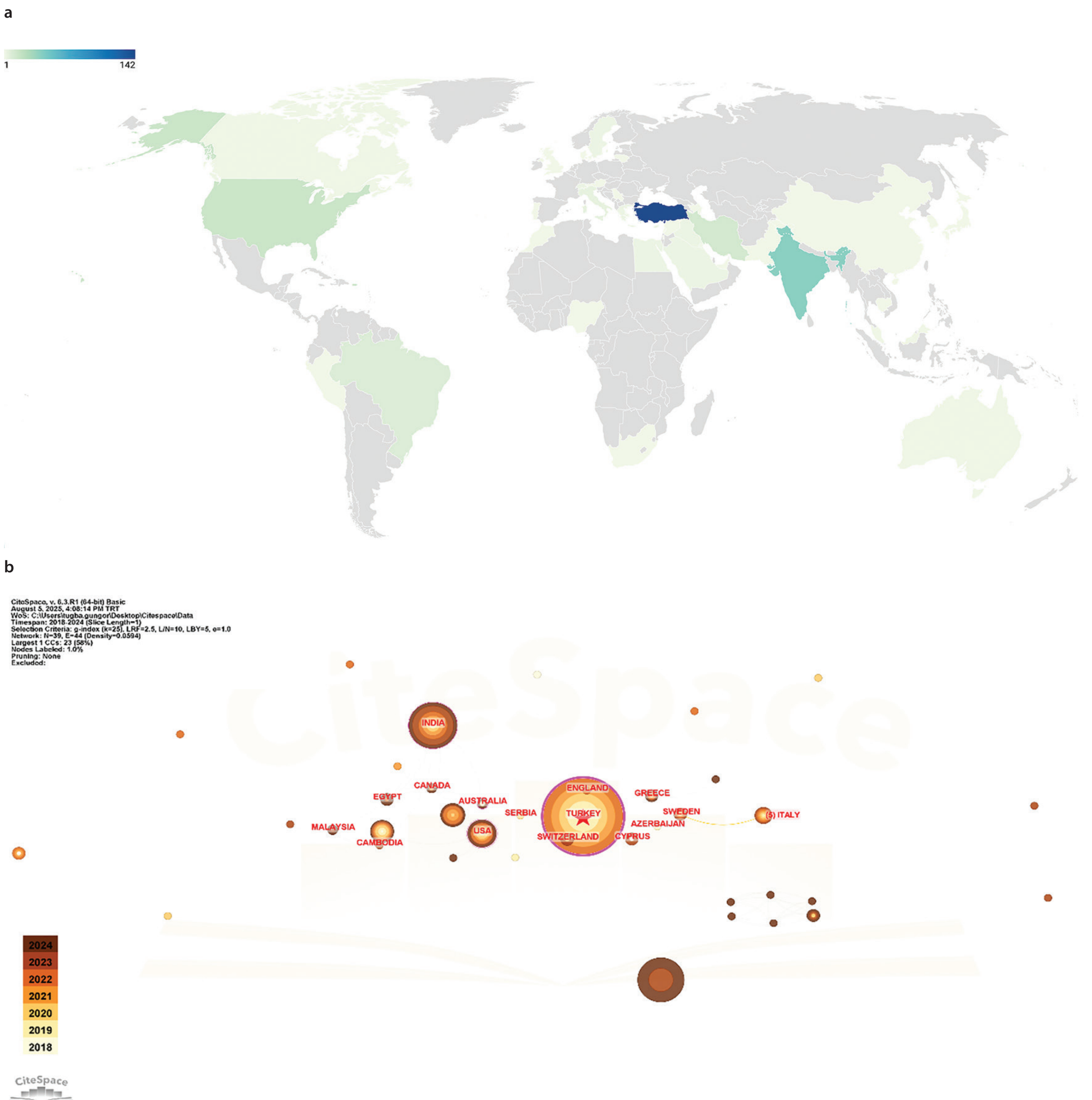

Figure 3. Geographical characteristics of Turkish Journal of Orthodontics contributions (2018-24). **(a)** World map showing geographical distribution of publications by country. Color intensity represents publication volume. The visualization was generated using Datawrapper. **(b)** International collaboration network visualized by CiteSpace 6.3.R1 and showing co-authorship patterns between countries. Node size represents publication productivity, and connecting lines indicate collaborative relationships.

knowledge base supporting TJO publications. Other frequently cited sources included the Journal of Orofacial Orthopedics, the Korean Journal of Orthodontics, and the Seminars in Orthodontics.

Keyword co-occurrence analysis

The network visualization map was generated using CiteSpace 6.3.R1 to illustrate the co-occurrence and temporal distribution of keywords (Figure 6). Each node represents a keyword, with node size proportional to occurrence frequency. The largest connected component comprises 169 nodes, representing 84% of the network. Lines connecting the nodes indicate co-occurrence relationships between keywords, with line thickness representing the strength of association (network density=0.0243). Node colors correspond to the year of first appearance, ranging from purple (2018) to dark red (2024), as indicated in the temporal legend.

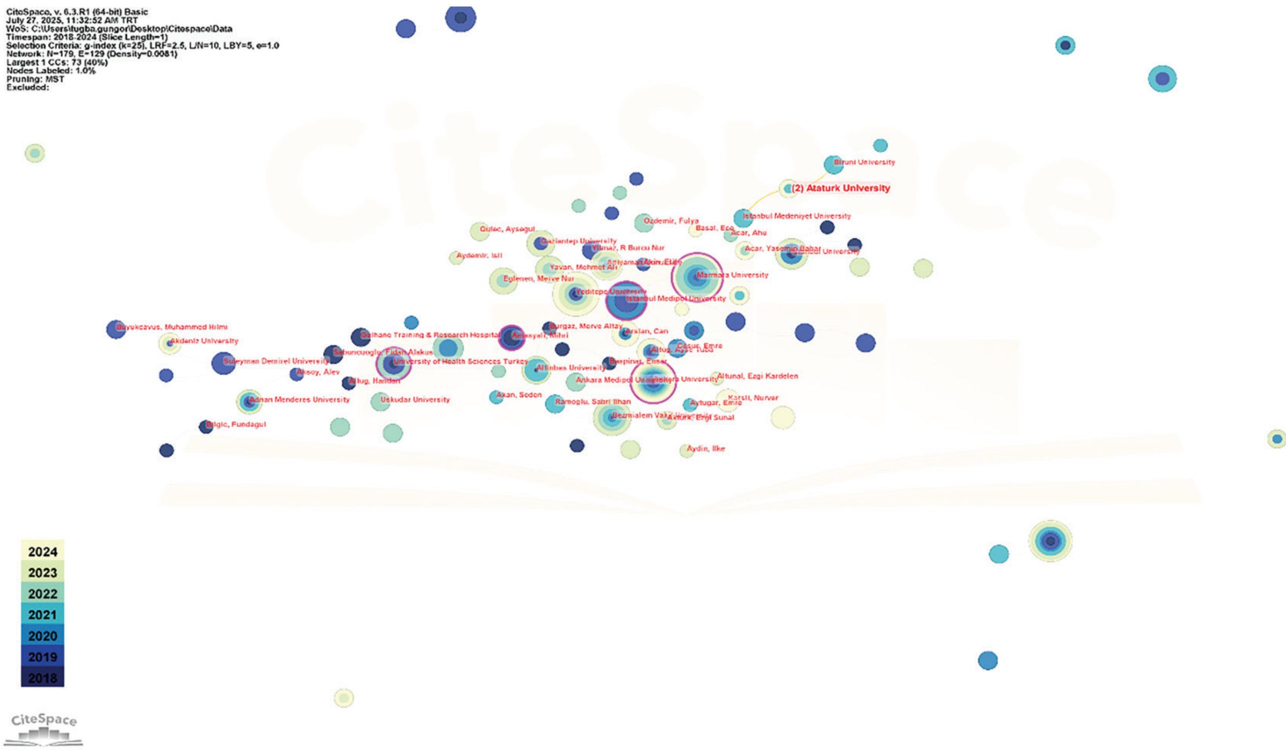

Figure 4. Institutional collaboration network of Turkish Journal of Orthodontics (2018-24). The network visualization, generated by CiteSpace 6.3.R1, shows research institutions and their collaborative relationships. Node size reflects publication volume, while betweenness centrality reflects the extent to which an institution acts as a bridge connecting otherwise separate collaboration clusters within the network. Temporal rings represent the progression of institutional activity over time.

Figure 5. Citation network of journals most frequently cited by Turkish Journal of Orthodontics publications (2018-24). Node size represents citation frequency, and lines indicate co-citation relationships. Temporal rings illustrate citation activity over time. The network was generated using CiteSpace 6.3.R1 (i.e., tree-ring history visualization).

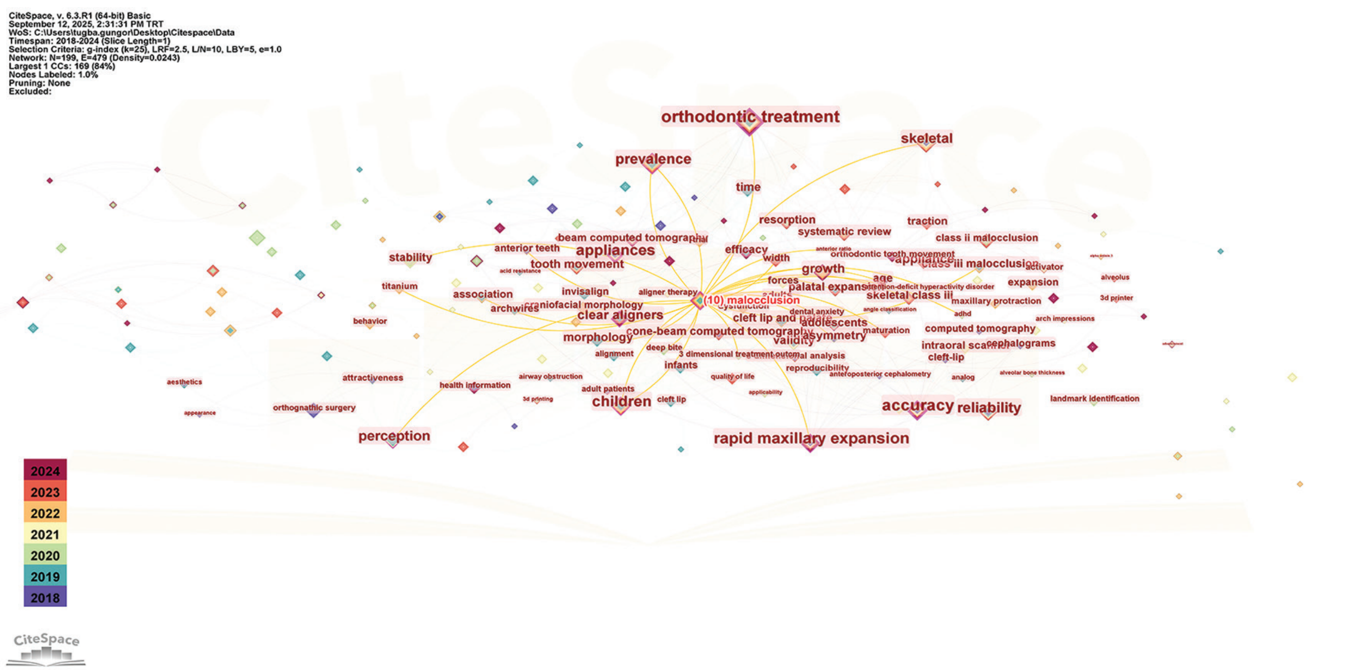

Figure 6. Keyword co-occurrence network generated using CiteSpace and based on publications indexed between 2018 and 2024. 169 keywords were grouped into five thematic clusters, with modularity (Q=0.69) and silhouette (S=0.86) values indicating a well-structured and internally consistent network. In the visualization, node size reflects keyword frequency, while link thickness represents the strength of co-occurrence between keywords. Colors correspond to the time of appearance of keywords, ranging from earlier publications (blue–green) to more recent (yellow–red) publications. The identified clusters represent major research themes, including orthodontic treatment modalities (e.g., appliances, clear aligners, and Invisalign), diagnostic approaches (e.g., cone-beam computed tomography and cephalograms), clinical outcomes (e.g., accuracy, reliability, and skeletal Class II/III malocclusion), treatment planning strategies (e.g., rapid maxillary expansion and tooth movement), and patient-related factors (e.g., children, adolescents, and cleft lip and palate).

Keyword co-occurrence analysis revealed 169 keywords forming five distinct thematic clusters (modularity Q=0.69, silhouette S=0.86), indicating well-defined research areas. Major thematic clusters include: orthodontic treatment modalities (e.g., appliances, clear aligners, and Invisalign), diagnostic approaches (e.g., cone-beam computed tomography and cephalograms), clinical outcomes (e.g., accuracy, reliability, and skeletal Class II/III malocclusion), treatment planning (e.g., rapid maxillary expansion and tooth movement), and patient-specific factors (e.g., children, adolescents, and cleft lip and palate).

The analysis showed a chronological shift in thematic emphasis. Earlier publications (2018-20) primarily focused on malocclusion, bonding, and growth assessment, whereas studies published after 2022 increasingly addressed clear aligner systems, digital orthodontic techniques, and artificial intelligence-based diagnostic tools.

DISCUSSION

This study provides a comprehensive bibliometric analysis of the publication characteristics and academic impact of TJO since its inclusion in WoS. Although TJO was indexed in WoS in 2017, this bibliometric analysis focused on data from 2018 onward, as the first year of meaningful citation accumulation typically follows the year of initial indexing.[3] A total of 244 articles published over a 7-year period were analyzed. The data show consistent publication activity, wider international participation, and increasing citation counts, pointing to the journal's ongoing growth and recognition in orthodontic research.

The analysis showed that the number of publications remained relatively stable between 2018 and 2024, ranging from 23 to 40 articles per year. Despite small variations, citation counts increased steadily, indicating growing scientific interest in studies published in TJO. The citation peak in 2024 indicates that papers from previous years have gained greater visibility within the orthodontic community. The apparent decline in 2025 could be attributed to incomplete data for that year, as full publication and citation records had not yet been incorporated at the time of analysis; therefore, it should not be interpreted as a true decrease in performance.

Publication activity during 2020 and 2021 overlapped with the COVID-19 pandemic, which interrupted clinical research and workflows, and reduced access to patient data.[12,13] Despite these difficulties, TJO maintained a relatively stable number of publications, demonstrating both editorial stability and the dedication of its contributors.

A clear change in publication patterns was observed after 2022. Although case reports were still being accepted for evaluation according to the journal's submission guidelines, no case reports were identified in the dataset after the third quarter of

2022, and systematic reviews began to appear in 2023.[14] Similar trends have been reported in the literature on orthodontics. Papageorgiou et al.[15] showed that the number of systematic reviews in orthodontics increased with time while Almotairy[16] reported a continued rise in systematic review publications across major orthodontic journals, highlighting their growing role in evidence-based practice. Case reports continue to have educational and clinical value, particularly in documenting rare or unique clinical scenarios.[17-19] However, because they are based on individual or limited clinical observations, their findings are inherently less generalizable and may attract fewer citations compared with broader analytical study designs.[20] In contrast, systematic reviews synthesize available evidence and typically provide higher-level evidence, potentially contributing to broader academic visibility and citation performance.[21]

An important finding of this analysis concerns the relationship between short-term and long-term citation metrics. Although TJO currently holds a clarivate impact factor of 1,5, the calculated average number of citations per article was 5.77, which is substantially higher than the impact factor would suggest. This discrepancy merits careful interpretation and highlights important distinctions between different bibliometric indicators.

The impact factor represents the average number of citations received in a particular year by articles published in the preceding 2 years, thus reflecting short-term citation performance within a narrow temporal window. This metric is inherently limited to recent publications and only captures the immediate impact.[22,23] In contrast, the average number of citations per article calculated in this analysis encompasses all publications from 2018 to 2024 and includes citations accumulated over variable time periods, thus providing a broader view of the journal's cumulative influence.

This substantial difference between the impact factor and the overall average number of citations per article suggests that many articles published in TJO continue to receive citations well beyond the 2-year citation window used to calculate the impact factor. This pattern indicates long-term relevance and sustained academic interest in the journal's content. Articles addressing foundational topics, methodological innovations, or comprehensive reviews can accumulate citations over extended periods as they become established references. Furthermore, the 5-year impact factor of 1.5 and the Scopus CiteScore of 2.0 provide additional perspectives on the journal's citation performance across different timeframes and indexing systems. The results indicate that TJO publications receive ongoing attention from researchers beyond their initial release. This finding underscores the value of using multiple bibliometric indicators rather than relying exclusively on the traditional 2-year impact factor when evaluating journal performance and research impact.

The h-index of 15 indicates consistent impact: 15 articles were cited at least 15 times, reflecting sustained rather than short-term influence.[24]

Among the top ten most-cited articles published by TJO between 2018 and 2025, the most common research themes were artificial intelligence applications, clear aligner therapy, temporomandibular disorders, and airway changes. The prominence of these topics can be explained by the growing popularity of clear aligner treatments and an increasing interest in the potential use of artificial intelligence in orthodontics. These topics represent modern, technology-driven areas that continue to attract attention and receive an increasing number of citations within recent orthodontic literature.[24] Furthermore, the number of publications related to clear aligner therapy more than quadrupled between 2020 and 2024, with the American Journal of Orthodontics and Dentofacial Orthopedics and the Angle Orthodontist being the leading outlets for this type of research.[25] The results of the present study are consistent with these findings and show that technology-oriented topics, such as artificial intelligence and aligners, have become major areas of interest in recent orthodontic research.

The methodological pattern in TJO publications reflects the diverse nature of orthodontic research. Most studies were clinical (52.5%), especially observational ones (32.8%), which are practical for evaluating treatment outcomes and growth patterns.[26] Since orthodontic treatment spans long periods, interventional studies are often difficult to conduct. In recent years, there has been a growing preference for retrospective study designs.[26] A considerable portion of TJO research (36.0%) was non-patient-based including finite element analyses, surveys, and bibliometric studies. These approaches show that orthodontic research is expanding beyond traditional clinical designs to include computational and secondary data analyses that do not require ethical approval.

The journal's multidisciplinary scope, evidenced by contributions from 26 disciplines beyond orthodontics, underscores its recognition that orthodontic treatment intersects with craniofacial growth, temporomandibular disorders, sleep-disordered breathing, psychological well-being, and systemic health considerations. This interdisciplinary approach enriches the journal's content and reflects contemporary understanding that orthodontic care requires the integration of knowledge across multiple domains.

From the perspective of international collaboration, TJO has a strong national base and a growing international reach. Most publications come from Türkiye (58.2%), reflecting the importance of the journal of the Turkish Orthodontic Society, with India emerging as the second-largest contributor (16.8%).

The network analysis revealed Türkiye's central position as a collaboration hub, maintaining partnerships across multiple continents including Asia (eg. India), North America (eg. USA and Canada), Europe (e.g., Switzerland, Sweden, UK, and Italy), and other regions (eg. Serbia, Malaysia, and Iran). This bridging role facilitates knowledge exchange between different research traditions and clinical approaches, potentially enriching the global orthodontic evidence base.

Contributions from 39 countries, including 22 single-publication countries (e.g., Cambodia, Lithuania, Morocco, Palestine, and Peru), highlight TJO's accessibility to researchers from emerging scientific regions. However, international co-authorship remains infrequent, indicating the need for stronger global collaborations to support knowledge exchange and innovation in orthodontic research.

Publications were predominantly produced by a small number of research-active universities, but contributions were shared across several institutions, indicating a balanced, healthy research environment. The five most productive institutions-Marmara University, Yeditepe University, Başkent University, Istanbul Medipol University, and Ankara University- collectively contributed 50 publications (20.5%), indicating a moderate rather than an extreme concentration. This pattern indicates a balanced research environment with several active institutions rather than one dominant center. The identification of Atatürk University as a central node in the institutional collaboration network, despite not ranking among the top five in absolute publication volume, highlights the distinction between productivity and influence. As such, research impact was not solely determined by publication numbers.

Authorship analysis showed an approximately balanced gender distribution (52.2% female, 47.8% male), with slightly more female than male authors. While male authors have traditionally dominated scientific publishing, recent studies indicate a positive shift in orthodontic research toward greater female representation.[27,28]

Most TJO papers (94.7%) were written by multiple authors, with an average of 3.5 authors per article, which is indicative of strong collaboration among researchers. Since most authors were from universities (92.4%), the journal primarily represents academic research, with limited contributions from clinicians in private practice.[24,25]

The most-cited articles and keyword-cluster analysis highlight the journal's thematic priorities and emerging research frontiers. The prominence of digital technologies among highly cited works, including automated cephalometric analysis, directly printed aligners, and artificial intelligence applications, reflects orthodontics' ongoing digital transformation.[29-31]

The keyword co-occurrence analysis revealed a temporal shift from traditional treatment approaches toward advanced digital technologies and patient-centered orthodontics. Traditional research topics, including skeletal classifications, growth assessment, bracket bonding, and maxillary expansion, maintained a consistent presence throughout the study period. The sustained research attention to temporomandibular disorders, sleep-disordered breathing, and airway considerations reflects an expanding recognition that orthodontic treatment intersects with broader health outcomes beyond dental alignment.

Study Limitations

Recent publications (2023-24) have had limited time to accumulate citations, which may lead to an underestimation of their eventual impact. Although the use of standardized vocabularies such as MeSH is recommended for bibliometric accuracy, the keywords analyzed in this study were predominantly author-defined rather than MeSH-standardized, which potentially affected the consistency of keyword clustering and co-occurrence mapping. In addition, WoS coverage might not fully capture all collaboration patterns, particularly those involving journals or emerging research groups not indexed in WoS, which could lead to an underrepresentation of specific types of collaborations.

CONCLUSION

This bibliometric analysis demonstrates that TJO has shown consistent growth in scientific visibility, citation impact, and international participation since its inclusion in the Web of Science. The journal reflects both established orthodontic research themes and emerging trends, particularly in digital orthodontics, clear aligner therapy, and artificial intelligence applications. The increasing presence of systematic reviews and multidisciplinary contributions further indicates a progressive shift toward evidence-based and collaborative research. Continued efforts to support international collaboration, methodological diversity, and rigorous reporting standards may further strengthen the journal's academic influence and long-term contribution to orthodontic literature.

Ethics

Ethics Committee Approval: As this study analyzed publicly available data from the Web of Science database, it was granted exempt status.

Informed Consent: Not applicable, as the study was based on publicly available bibliometric data and did not involve human participants.

Footnotes

Author Contributions: Concept - A.A., B.S.A.; Design - A.A., B.S.A.; Data Collection and/or Processing - A.A., T.G., B.S.A.; Analysis and/or Interpretation - A.A., T.G., B.S.A.; Literature Search - A.A., B.S.A.; Writing - A.A., B.S.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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TURKISH JOURNAL OF ORTHODONTICS

Erratum

Authorship Correction

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Turk J Orthod. 2026;39(1):10-16

After publication of the article entitled "Assessing Best Locations for Mini-Implants in the Mandibular Symphysis Based on Different Mandibular Growth Patterns: A CBCT Study" in Turkish Journal of Orthodontics, an authorship correction was requested regarding the author list, author order, and author contribution statement.

Following editorial evaluation and written approval from all authors, Dr. Aniket Hedaoo has been added to the author list as the first author. Accordingly, the author order and author contribution statement have been updated.

All authors have provided written approval for this correction. The online version of the article, including the PDF, HTML, and metadata records, has been updated accordingly.

Published on page 10;

Gaurav Agrawal, Sumit Gandhi, Shaheen Hamdani, Harsha Malhotra, Shrushti Jadhao, Preeti Paryani

Cite this article as: Agrawal G, Gandhi S, Hamdani S, Malhotra H, Jadhao S, Paryani P. Assessing best locations for mini-implants in the mandibular symphysis based on different mandibular growth patterns: a CBCT study. Turk J Orthod. 2026; 39(1): 10-16

Corrected page 10;

(The corrected parts are given in bold)

Aniket Hedaoo, Gaurav Agrawal, Sumit Gandhi, Shaheen Hamdani, Harsha Malhotra, Shrushti Jadhao, Preeti Paryani

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Published on pages 10-16;

Agrawal et al. Locations for Mini-Implants in Mandibular Symphysis in Different Growth Patterns

Corrected pages 10-16;

(The corrected parts are given in bold)

Hedaoo et al. Locations for Mini-Implants in Mandibular Symphysis in Different Growth Patterns

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